Automatic classification of high grade brain tumour MRI for improved resection and therapy planning

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Background

Contrast enhanced MRI (CE MRI) is often used as the "gold standard" for high grade brain tumour (World Health Organisation [WHO] grade III and IV brain tumour) resection and radiotherapy planning. The mortality rate of patients with high grade brain tumours is high, with a median survival time of only 12 to 15 months for grade IV brain tumour and 2 to 3 years for grade III brain tumour[1]. A factor contributing to this poor outcome is the relatively low sensitivity of CE MRI to tumour tissue as well as it limitation in differentiating tumour recurrence from chemo-radiotherapy induced injury. Positron emission tomography (PET) imaging using tracers such as 4-dihydroxy-6-[18F]-fluoro-L-phenylalanine (FDOPA) has been shown to be clinically useful for detecting low grade and high grade brain tumours[2] with the limitations of low resolution and poor signal-to-noise ratio. This work tests the hypothesis that sensitivity of MRI to high grade brain tumours can be improved by using computer aided analysis by utilising supervised classification techniques to estimate the probability of tumour tissue in each voxel in the MR image, independently (i.e. creating a "risk map"). The method is validated quantitatively and qualitatively against registered FDOPA-PET images.

Materials and Methods

Dataset: Datasets from 10 high grade brain tumour patients (age range 47 to 71 years) were acquired for the study. Eight patients had surgical resection of their tumours. Five of those also received standard chemo-radiation therapy. Data were collected in three time points: for all 10 patients before resection (T1), 6 datasets, were collected 4 weeks post-resection post-therapy (T2), and 2 datasets (of the 6 T2 datasets), were collected 4 months post resection (T3). Each dataset included four MRI scans, all acquired in the same imaging session, namely a DCE MRI, ADC, and SWI map and an FDOPA PET scan. All MR images were acquired using a 3T Siemens TimTrio (Siemens, Erlangen, Germany) using standard sequences.

Feature extraction: prior to feature extraction all images of each dataset were registered to the 4th DCE-MRI post contrast volume. Then a kinetic model of enhancement (KME) [3] and a pharmacokinetic model (PKM) [4] were fitted to each contrast enhancement curve of each voxel, using non-linear Levenberg-Marquardt optimisation, and a set of ten features was extracted for each voxel in the image: Maximum KME enhancement time[5], Maximum KME relative enhancement [5], Contrast agent KME wash-in rate [5], Contrast agent KME wash-out rate [5], Area under the KME enhancement curve [6], K_{trans} (from PKM), V_e (from PKM), V_p (from PKM), ADC value and the Contrast Enhanced SWI (CE-SWI) value - normalised to yield maximum of 1 in the image.

Classifier training and validation: Following the feature extraction a training set of approximately 100 voxels (50 tumour, 50 benign) was selected from each T1 dataset. A manual delineation of the tumour was performed by an experienced nuclear-medicine physician for each dataset to assist with the selection of samples. A logistic regression classifier was then trained on the samples from all T1 datasets but one, and was applied to all voxels in all time points of the 'left-out' patient.

Results

Classifier validation: As a preliminary stage the performance of the classifier was tested quantitatively on the tagged sample points using a leave-one-out strategy. The validation provided an area under the receiver operating characteristic (ROC) curve of 0.85±0.01with minimum classification error of 0.2

Tissue classification: The accuracy of the resulting risk maps were compared both quantitatively and qualitatively with the corresponding FDOPA defined tumour extent. As a quantitative measure, the Pearson correlation between the FDOPA-PET delineated tumour volumes was compared to the MR contrast enhancement and to the risk map defined values. The statistical difference between the two sets of correlation was tested using Wilcoxon rank-sum test with H_1 that the correlation between FDOPA and the risk map is higher and the null hypothesis (H_0) that they are equal. The result of the test was that H_0 can be rejected with p-value $<10^{-4}$ level of significance.

Qualitative evaluation of the results was also performed by visually assessing the findings from the risk map compare to the CE-MRI while using the FDOPA as a base-line. Sample results are shown in Figure 1.

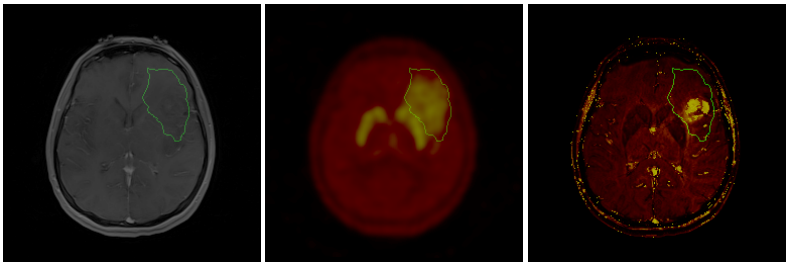

Figure 1: Classification results of a grade III patient (T1): no contrast enhancement is evident in the CE-MR (left) while the FDOPA clearly shows the extent of the tumour (centre). The risk map shows some evidence of the tumour (right). The manual delineation boundary is imposed in all images. Bright orange correspond to high risk (i.e. higher than 0.75) while dark red corresponds to low risk (i.e. lower than 0.5).

Conclusions

The results of the quantitative and qualitative evaluation of the method suggest that the risk maps generated from multiple MR images provide higher sensitivity to brain tumour tissue than CE MRI alone. Thus the resulting risk maps can be used as a tool for improved chemo-radiation therapy planning and resection planning for high grade brain tumours. Also, the method has the potential to predict regrowth and indicate infiltration of tumour tissue in the brain better than CE MRI.

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References

[1]P. Y. Wen and S. Kesari, New England Journal of Medicine, 2008, 359(5):492-507
[2]C. Schiepers, W. Chen, T. Cloughesy, M. Dahlbom and S. C. Huang, Journal of Nuclear Medicine, 2007, 48(10):1651
[3]Y. Gal, A. Mehnert, A. Bradley, K. McMahon and S. Crozier, IEEE Engineering in Medicine and Biology Society (EMBC), 2007, 71-74
[4]E. Eyal and H. Degani, NMR in Biomedicine, 2009, 22(1):40-53
[5]Y. Gal, A. Mehnert, A. Bradley, D. Kennedy and C. Stuart, Journal of Computer Assisted Tomography, 2010, 35(5):645-654
[6]S. Bisdas, T. Naegele, R. Ritz, A. Dimostheni, C. Pfannenberg, M. Reimold, T. S. Koh and U. Ernemann, Academic Radiology, 2011, 18(5):575-583