Prediction of Epilepsy Development in Traumatic Brain Injury Patients from Diffusion Weighted MRI

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1 INTRODUCTION

Post-traumatic epilepsy (PTE) is a form of acquired epilepsy that results from a traumatic brain injury (TBI) caused by an external force, for example height falls, motor vehicle accidents, etc. A person with PTE suffers unprovoked and recurrent post-traumatic seizures (PTS) more than one week after the TBI. Effective pharmacological treatments in the prevention or treatment of symptomatic seizures in patients with PTE does not currently exist, therefore the epilepsy community has an urgent need to find reliable biomarkers of PTE [5]. Currently, the Epilepsy Bioinformatics Study for Antiepilepticogenic Therapy (EpiBioS4Rx) is pioneering this work with the aim to design and perform preclinical trials of antiepileptogenic therapies followed by future planning of clinical trials. Diffusion weighted imaging (DWI), in combination with machine learning techniques, has contributed considerably to the identification of white matter regions affected by neurological conditions in their early phases, especially with the growing dissemination of innovative diffusion tensor imaging (DTI) techniques for tractography [3].

Many DWI studies are based on the measure of quantitative indices, such as fractional anisotropy (FA), radial diffusivity (RD), and mean diffusivities (MD) that characterize water diffusion in the brain. The corpus callosum, superior coronal radiata, cingulate bundle, superior and inferior longitudinal fasciculi, and arcuate fasciculus are the most susceptible white matter tracts after TBI. Moreover, structural and functional alterations and disconnections related to seizure development after TBI are found in the thalamus, hippocampus, cingulate gyrus, precentral gyrus, postcentral gyrus, and middle and inferior frontal and temporal gyrus [1, 2, 4].

In this work, we have analyzed a sample of 14 patients from the EpiBioS4Rx cohort: 7 who develop PTE and 7 who have not developed PTE. We apply a tract-based spatial statistic (TBSS) analysis on the diffusion data to obtain FA values to train two support vector machine (SVM) models to predict which TBI patients have developed epilepsy. Our approach, tested on these 14 patients with a leave-two-out cross-validation, allowed us to obtain an accuracy of 0.857 ± 0.18 (with a 95% level of confidence), demonstrating it to be potentially promising for the early characterization of PTE.

CCS CONCEPTS

- Applied computing → Imaging
- Computing methodologies → Support vector machine

KEYWORDS

Traumatic brain injury, diffusion tensor imaging, epilepsy prediction, tract-based spatial statistic, support vector machine.

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According to the EpiBioS4Rx protocol, for each enrolled patient, different MRI sequences are acquired within 1-18 post-injury days: T1 MRI, resting state blood oxygenation level dependent (BOLD) functional magnetic resonance imaging (rs-BOLD MRI), DWI, gradient echo/ susceptibility weighted imaging (GRE/SWI), T2, and T2-weighted fluid attenuated inversion recovery (FLAIR).
The acquired DWI scans of each patient correspond to multiple diffusion gradient values and directions. This DWI data is processed in the FMRIB Software Library (FSL) [6]. Next, FSL’s Brain Extraction Tool (BET) is applied to create a binary brain mask. Afterwards, FSL’s Diffusion Toolbox (FDT) is used to estimate DTI parameters for FA, MD, etc. image maps. The FA images are then slightly eroded in FSL to remove brain-edge artifacts and possible outliers. An example cleaned image is seen in Fig. 1.

In the next phase, the TBSS analysis is performed following the ENIGMA DTI pipeline [7]. The cleaned FA images are first registered to the standard ENIGMA DTI FA space. Following registration, an FA skeleton is generated for each projected FA map, using the ENIGMA DTI FA standard distance map. Along 46 different tracts in each skeleton, obtained from the JHU atlas, the mean FA values are calculated. In this work, we have chosen the mean FA values of the left uncinate fasciculus and the right cingulum, the two tracts that demonstrate the most distinctive difference between the two groups in our sample, and are also potentially important biomarkers for PTE prediction [1]. A sample skeleton of a patient’s brain, with the chosen tracts, is shown in Fig. 2.

3 EXPERIMENTAL RESULTS

The scores of the selected features for the two groups are visualized in Fig. 3. As evident, the groups appear to be well separable. Accordingly, we tested two SVMs on the data: one with a linear kernel, and the other with a radial basis function (RBF) kernel, defined by a gamma value of 0.5. The testing is based on a leave-two-out cross-validation, where for each round, the test set contains one patient who will develop at least one seizure, and another who will not develop seizures. The analysis results for this sample, for a 95% level of confidence, are tabulated in Table 1. As we can observe, the linear SVM actually does a better job in predicting if a patient develops PTE, in terms of both accuracy and F1 score.

4 CONCLUSION

In this preliminary work, we have demonstrated that a linear SVM trained on FA values derived from a TBSS analysis of diffusion imaging has the potential to detect PTE at an early stage, with a high degree of accuracy and reliability. A limitation of this work rests in the possible inclusion of false negatives, since here we do not have the follow up data for all patients for the entire two years.

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REFERENCES

[1] Rachael Garner, Marianna La Rocca, Giuseppe Barisano, Arthur W Toga, Dominic Duncan, and Paul Vespa. 2019. A machine learning model to predict seizure susceptibility from resting-state fMRI connectivity. In 2019 Spring Simulation Conference (SpringSim). IEEE, 1–11.

[2] Rachael Garner, Marianna La Rocca, Paul Vespa, Nigel Jones, Martin M Monti, Arthur W Toga, and Dominic Duncan. 2019. Imaging biomarkers of posttraumatic epileptogenesis. Epilepsia 60, 11 (2019), 2151–2162.

[3] Marianna La Rocca, Nicola Amoroso, Alfonso Monaco, Roberto Bellotti, Sabina Tangaro, Alzheimer’s Disease Neuroimaging Initiative, et al. 2018. A novel approach to brain connectivity reveals early structural changes in alzheimer’s disease. Physiological measurement 39, 7 (2018), 074005.

[4] Marianna La Rocca, Rachael Garner, Kay Jann, Hosung Kim, Paul Vespa, Arthur W Toga, and Dominique Duncan. 2019. Machine learning of multimodal MRI to predict the development of epileptic seizures after traumatic brain injury. In 2019 Medical Imaging with Deep Learning Conference (MIDL). MIDL, 1–4.

[5] Loretta Piccenna, Graeme Shears, and Terence J O’Brien. 2017. Management of post-traumatic epilepsy: An evidence review over the last 5 years and future directions. Epilepsia open 2, 2 (2017), 123–144.

[6] Stephen M Smith, Mark Jenkinson, Heidi Johansen-Berg, Daniel Rueckert, Thomas E Nichols, Clare E Mackay, Kate E Watkins, Olga Ciccarelli, M Zaheer Cader, Paul M Matthews, et al. 2006. Tract-based spatial statistics: voxelwise analysis of multi-subject diffusion data. Neuroimage 31, 4 (2006), 1487–1505.

[7] Jason L Stein, Sarah E Medland, Alejandro Arias Vasquez, Derrek P Hibar, Rudy E Senstad, Anderson M Winkler, Roberto Toro, Katja Appel, Richard Barreto, Ørjan Bergmann, et al. 2012. Identification of common variants associated with human hippocampal and intracranial volumes. Nature genetics 44, 5 (2012), 552–561.