Surface and voxel-based analysis of multi-modal quantitative MRI for pre-surgical evaluation of epilepsy patients

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Introduction

Temporal lobe epilepsy (TLE) is a common form of intractable, or drug-resistant epilepsy, affecting close to one third of epilepsy patients. Surgical treatment by an anterior temporal lobectomy, which involves resection of both the neocortex and mesial structures, is often performed in these cases [1]. Specific targeting of the epileptogenic zone might allow one to tailor the resection to decrease morbidities with the same seizure free outcome. However, accurate localization with conventional EEG and MRI techniques is challenging, and in many cases diagnostic MRI scans are found to be negative. Multi-modal quantitative MRI, such as relaxometry and diffusion tensor MRI can detect subtle abnormalities by comparison against a population-based atlas of healthy controls [2]. Voxel-based atlases encompassing the entire brain can be generated using volumetric brain registration, however, these algorithms have difficulty aligning the cortical regions because of complex and varied folding patterns. Surface-based approaches, although limited to the analysis of cortical regions, alleviate this issue by reconstructing and mapping the cortical surface to a spherical topology for registration. The objective of this work is to evaluate the use of multi-modal quantitative MRI in patient-specific analyses, identifying and localizing structural abnormalities, comparing both voxel-based and cortical surface-based approaches.

Methods

Temporal lobe epilepsy patients who had been discussed at multidisciplinary surgical rounds and found to be candidates for anterior temporal lobectomy were recruited for this study (N=9), which included 4 MRI-positive cases (3 MTS, 1 tumour), and 5 MRI-negative cases. They were scanned pre-operatively along with age-matched healthy controls (N=20) on a 3T MRI (GE Discovery MR750) with DESPOT1 and DESPOT2 [3] fast T1 and T2 mapping sequences (1mm isotropic), and diffusion tensor imaging (DTI, 41-directions, 2.5mm isotropic). The diffusion-weighted images were corrected for EPI distortions using diffeomorphic registration [4] to the T1 map prior to tensor estimation and computation of FA/MD. For the voxel-based analysis, T1w images were co-registered using a groupwise B-spline non-rigid registration, then the quantitative MRI images were transformed to the average atlas space. For the surface-based analysis, Freesurfer image analysis suite [5] was used to generate cortical surface reconstructions and perform surface-based registration. The co-registered quantitative metrics were sampled onto each subject's cortical surface at the gray-white boundary and these were resampled to the common surface-based atlas space for statistical analysis. For both approaches, the SurfStat MATLAB toolbox [6] was used to perform univariate vertex-wise statistics for each quantitative metric, using cluster-wise and random-field theory correction and 5mm FWHM Gaussian filtering. We compared each individual to the control group to obtain individualized significance maps. To summarize the results, we computed a score based on the proportion of significant voxels with respect to the total volume of each region. We used temporal and extra-temporal regions in each hemisphere; and for the surface-based results, only voxels on the GM/WM boundary were counted. These scores were computed for each patient, and also for each control using a leave-one-out approach.

Results & Discussion

Figure 1 shows the distribution of scores in the ipsilateral and contralateral temporal lobe, comparing patient group, metric, and surface-vs-voxel approach. Both MRI-negative and MRI-positive subjects had significantly higher scores than the controls in all 4 MRI metrics (two-sample T-test, P<0.05). Scores were higher in the ipsilateral temporal lobe for MRI-negative patients, demonstrating the potential to detect abnormalities in cryptogenic cases where lesions are not seen conventionally. The scores for both surface and voxel-based approaches were very similar, with the only significant difference being in the MD scores of the controls (P=0.03). This is remarkable since the surface-based analysis is restricted to the GM/WM boundary, and thus only uses approximately 15% of the voxels, indicating that the GM/WM boundary is an important region for investigation. The voxel-based analysis does however provide additional information in white matter regions, as is shown in Figure 2 which demonstrates an example of clusters found in an MRI-negative and MRI-positive patient.

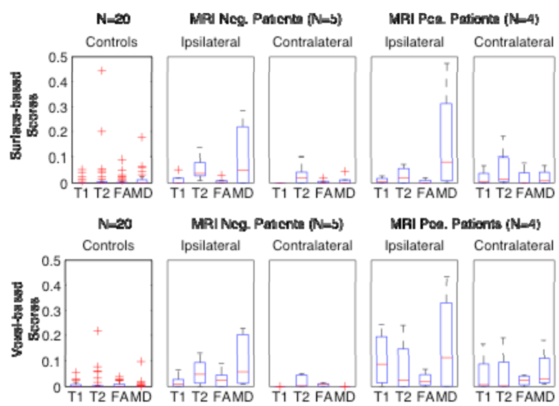

Figure 1: Scores for the temporal lobe region comparing surface-based and voxel-based analysis on the patients and controls.

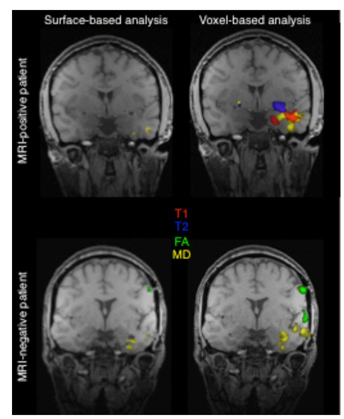

Figure 2: Statistically significant clusters on an MRI-positive patient and an MRI-negative patient.

Conclusion

We have described and evaluated both voxel-based and surface-based structural analysis approaches using quantitative MRI techniques that can provide patient-specific maps for temporal lobe epilepsy. Both approaches proved more sensitive in detecting brain abnormalities of epileptic patients than diagnostic MRI. This technique, with further histological validation using resected specimens [7], could replace invasive sub-dural or depth electrode monitoring for assessing involvement of neocortical regions and thus inform suitability of selective resection strategies.

References

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