Clinically-Driven Multimodal Imaging of Traumatic Brain Injury Using Semi-Automatic Segmentation in 3D Slicer

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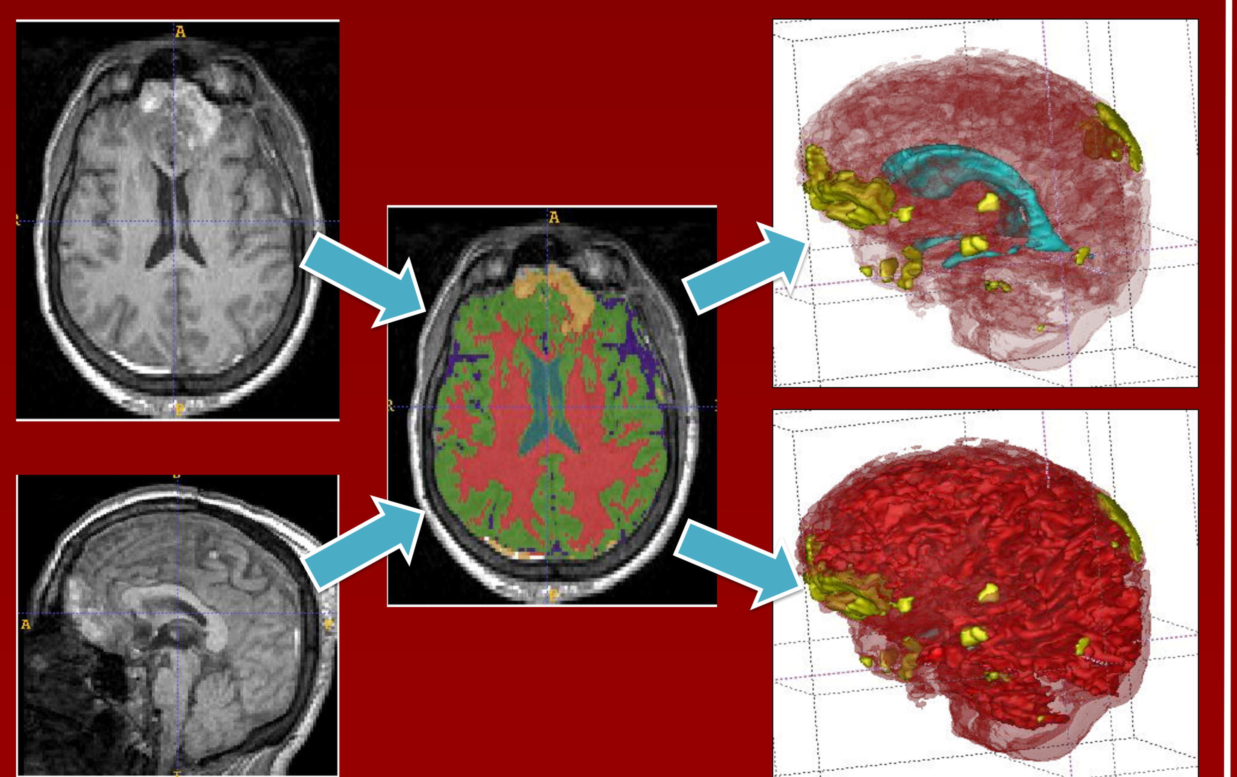

Figure 1. Semi-automatic segmentation of a TBI volume in 3D Slicer. T1 image quality is poor, as a result of motion, poor contrast, etc. First, all image volumes (first column) are co-registered to the anatomic T1 volume, whereafter segmentation is performed to obtain tissue classifications (white matter, gray matter, CSF, ventricles and lesions – second column). Finally, the 3D models are created in 3D Slicer.

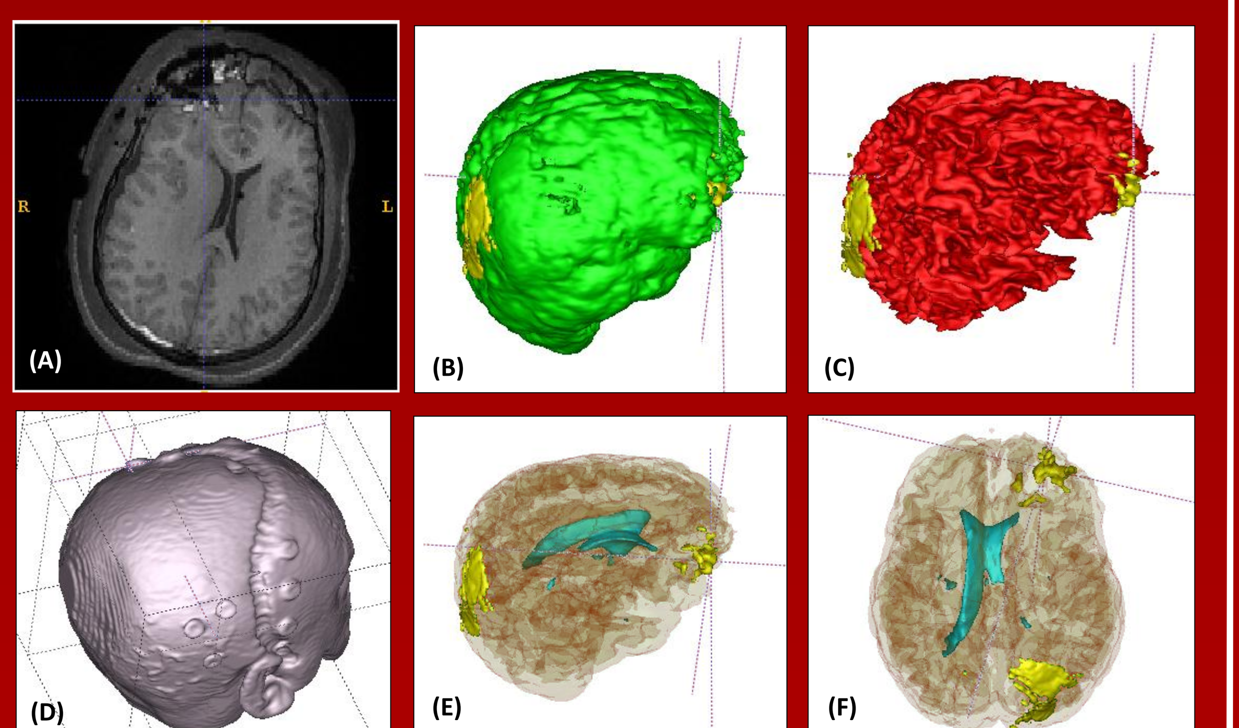

Figure 2. Semi-automatic segmentation of a TBI volume in 3D Slicer. Challenges associated with this segmentation include low T1 image quality (low contrast, non-isotropic voxels) and brain damage. Brain segmentation was performed automatically, followed by user-supervised level-set segmentation of the lesions and ventricles. T1 hyperintense regions are shown in yellow. (A) T1 image; (B) gray matter volume; (C) white matter volume; (D) scalp segmentation; (E,F) ventricles and lesion segmentation

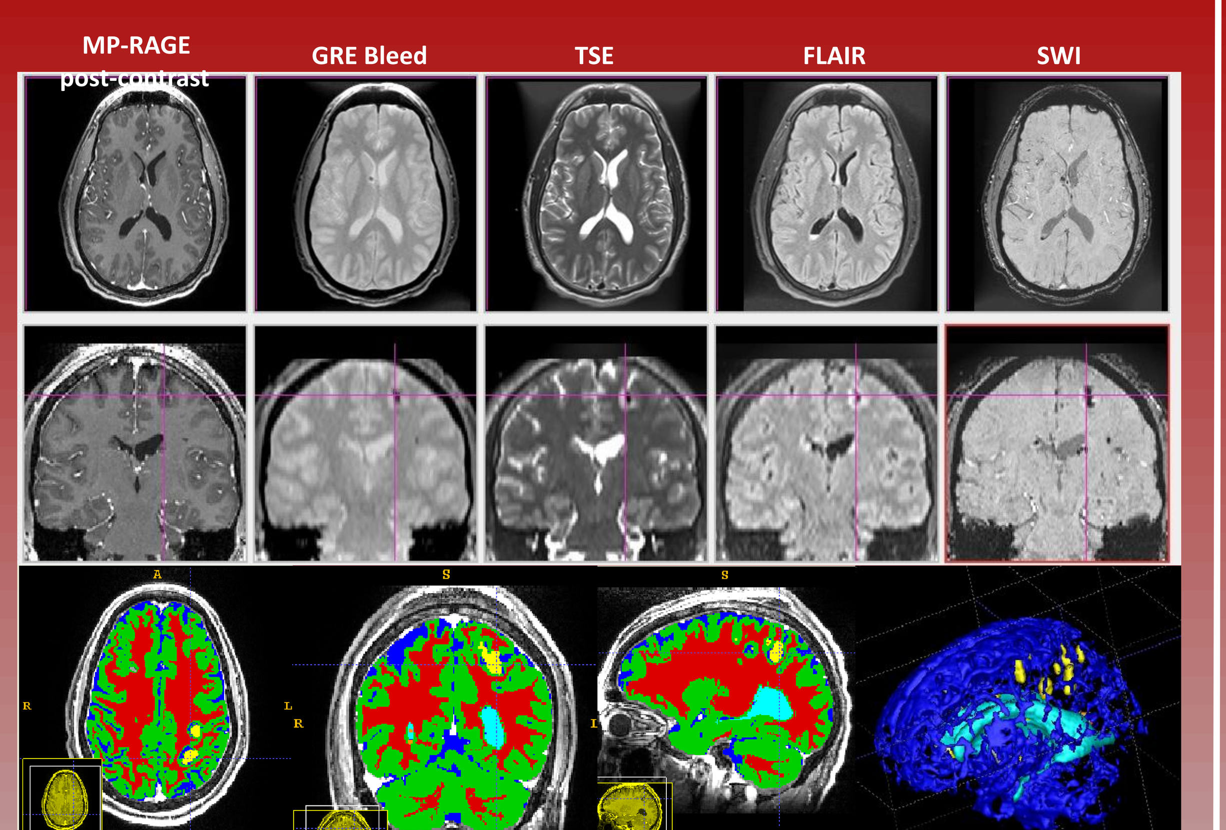

Figure 2. Multimodal segmentation of several MR volumes acquired from a TBI patient. The segmentation method being used (Atlas Based Classification, ABC) performs co-registration of all input modalities (5 MRI channels, in this case) and atlas-based segmentation of brain tissue and CSF. Bias-correction (all modalities) and brain-stripping is an integrative, automatic part of ABC. White matter lesions and ventricles were segmented via post-processing using level-set segmentation. (A) 5 MR image channels; (B) automatic tissue classification; (C) 3D model showing ventricles, lesions.

INTRODUCTION

- an estimated 1.7 million Americans sustain a traumatic brain injury (TBI) every year [1]
- the use of automatic segmentation for the clinical investigation of TBI remains an elusive goal because such methods are insufficiently robust to accurately capture TBI-related changes in brain anatomy
- despite recent progress in image analysis, it remains difficult to quantify TBI-related brain insults multi-modally, especially for improving clinical outcome metrics
- to address the urgent need for clinically-oriented TBI analysis tools, we have used multimodal, automatic TBI analysis methods with a view toward assessing clinical improvement

METHODS

- we employ the NA-MIC Kit and 3D Slicer platforms [2, 8, 9] to obtain metrics of pathology and changes due to therapy and/or recovery
- processing includes segmentation of lesions, hemorrhage, edema and other pathology using Atlas Based Classification (ABC)
- ABC is a robust automatic segmentation framework which includes multimodal image registration, model-based bias field correction, tissue classification and outlier detection [2, 4-7]
- the ABC paradigm is considerably more suitable for TBI volume segmentation compared to standard methodologies
- longitudinal changes are assessed by registration and joint segmentation of baseline and follow-up data for the ultimate purpose of performing longitudinal analysis
- our tools allow cross-correlation of multimodal metrics from structural imaging (cortical thickness, volume, lesions) and DTI with clinical outcome variables (time since injury, age, gender, etc.)
- neuroimaging data are drawn from the LONI Image Data Archive (IDA), a comprehensive archive comprised of a number of funded projects [3]

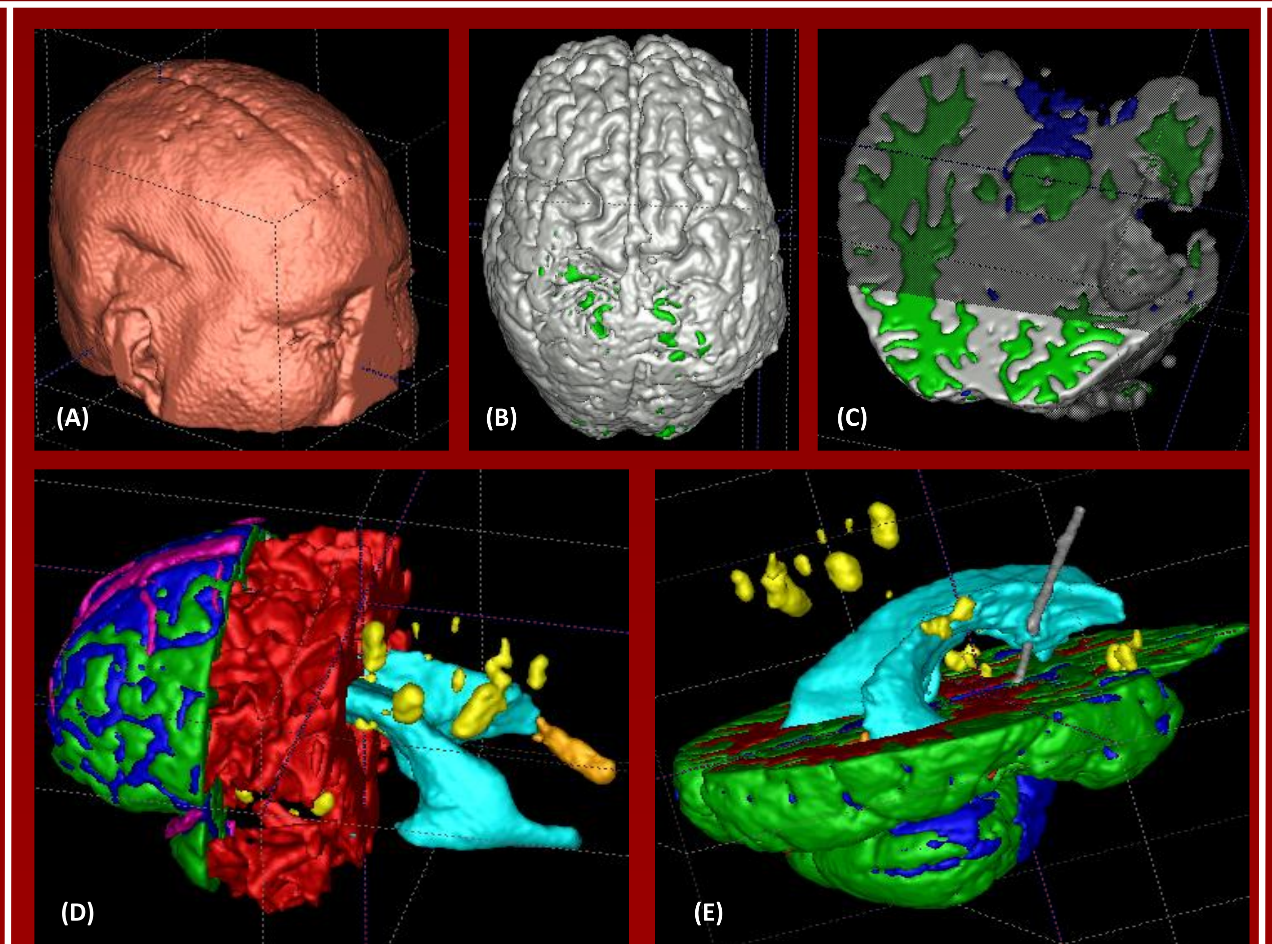

Figure 4. (A) Automatic segmentation of the scalp surface for a TBI patient performed using 3D slicer software. (B) Model of the gray matter surface, rendered in 3D Slicer. (C) Cross-section through the anatomy reveals tissue types. (D, E). 3D views of segmented tissues, with white matter (red), gray matter (green), CSF (blue), ventricles (cyan) and lesions (yellow).

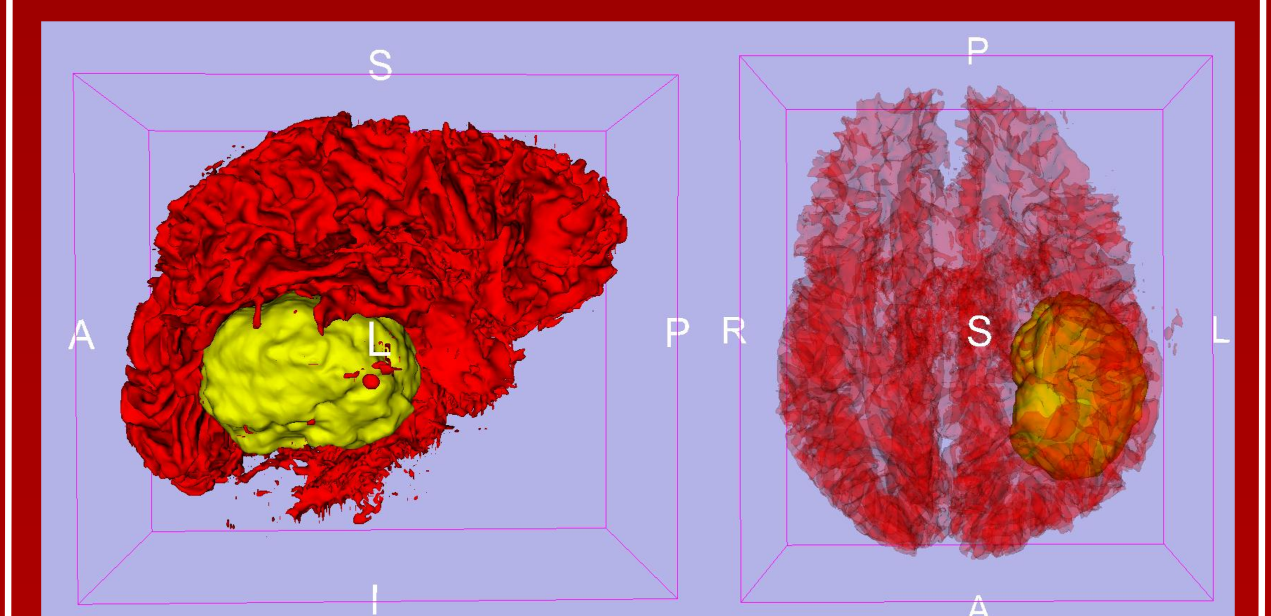

Figure 5. Sample white matter and lesion segmentation, showing opaque models (left) of the white matter (red) with lesion (yellow) and transparent models (right).

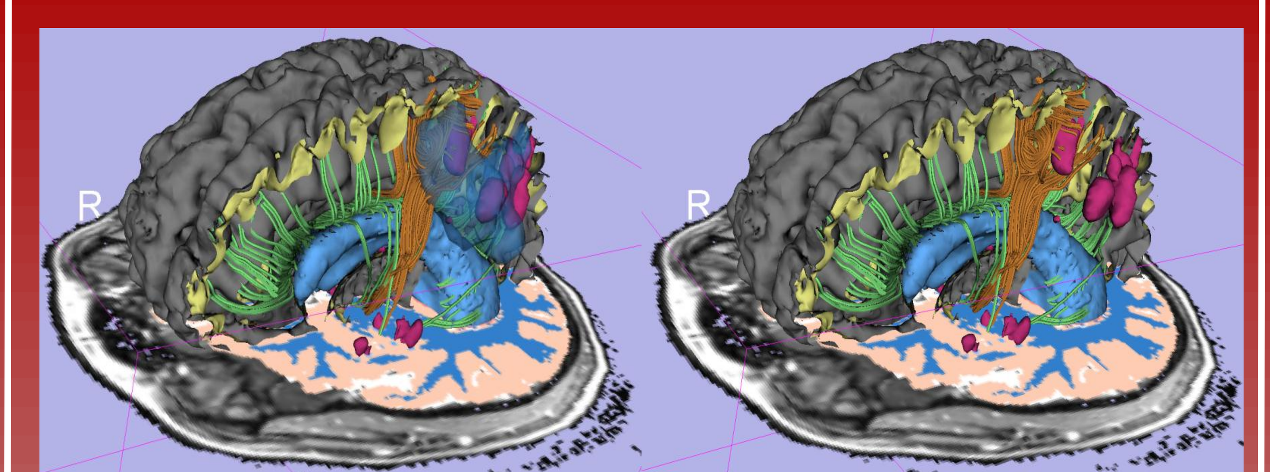

Figure 5. Tractography and joint display of segmented objects and MRI. The ABC algorithm performs the co-registration of structural modalities to DTI (baseline image registered to TSE), which allows TDI tensor field and structural images to be available in the same coordinate system.

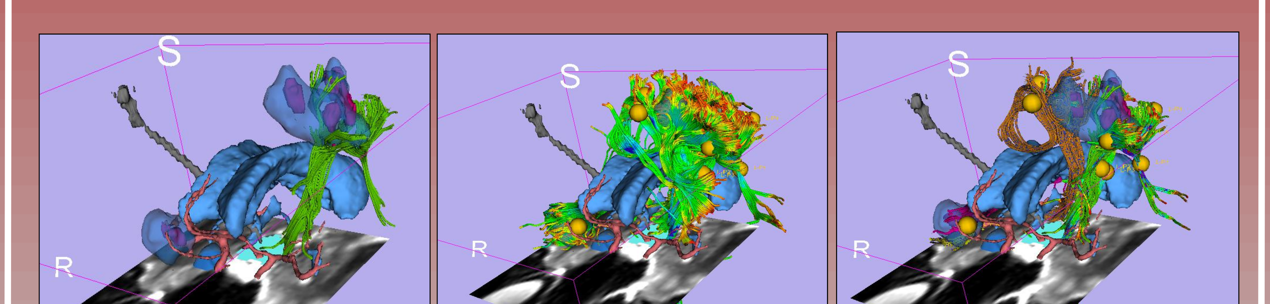

Figure 6. Visual assessment of multi-modality imaging of 3D fiber tracts and morphometry provides proof of 3D Slicer capabilities to perform TBI MR image analysis. Such analysis may potentially identify specific targets for neurological testing; this may allow the clinician to deploy neuropsychological tests based on hypotheses from imaging.

RESULTS

- 3D Slicer and the NA-MIC Kit are applicable to the analysis of TBI neuroanatomy to investigate alterations in cortical thickness aand white matter changes
- Slicer software tools being developed allow us to obtain multimodal results for the analysis of neurological concomitants associated with TBI
- metrics can be extracted for uni- and multivariate modeling to provide additional insights about neuro-anatomical changes and clinical outcome variables
- multimodal data processing solutions are to be made openly available, with accompanying training materials via the NA-MIC web site, and compliant with the NA-MIC open-source policies

CONCLUSIONS

- we envision NA-MIC Kit workflows to be suitable for TBI clinical practice and patient monitoring, particularly for assessing TBI damage and measuring neuroanatomical change over time
- with knowledge of location, extent, and degree of change, metrics can be associated with clinical measures and subsequently used to suggest viable treatment options for individual subjects against patterns that are typical TBI populations

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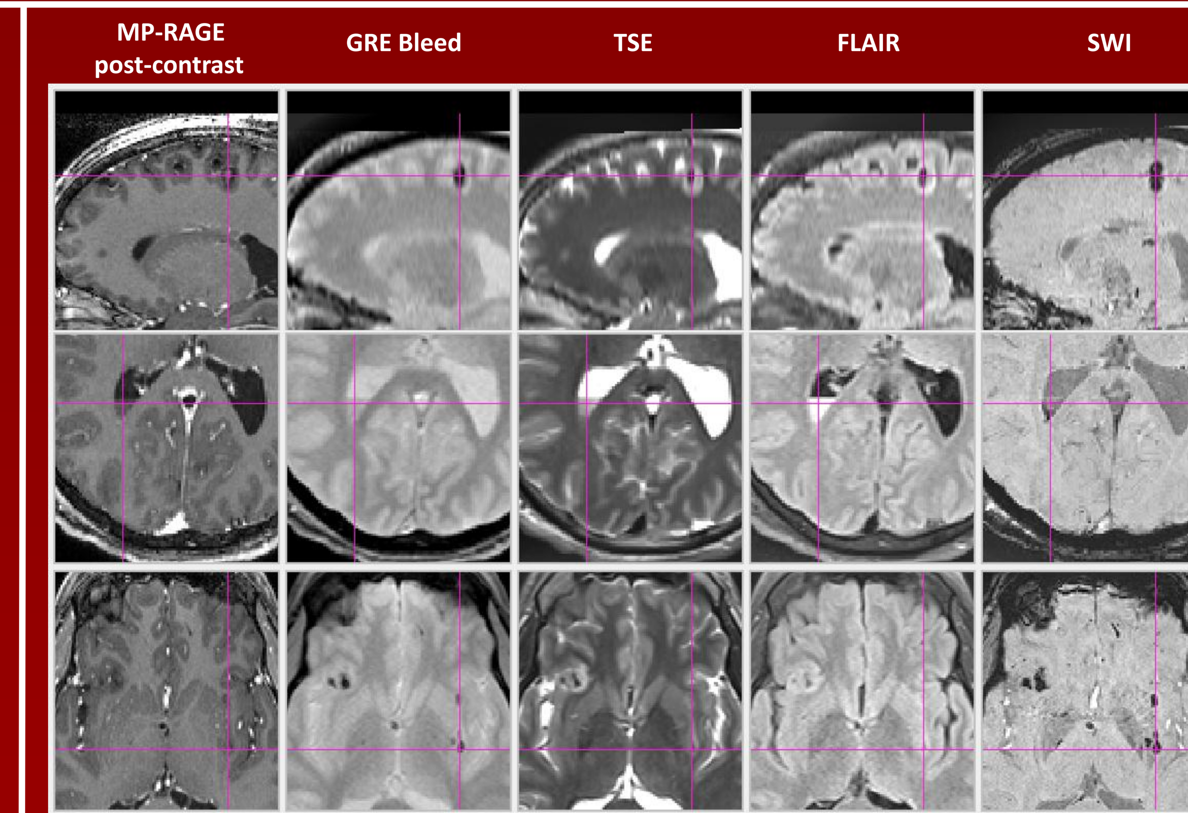

Figure 7. Co-registration of structural MRI volumes using 3D Slicer and ABC algorithm.

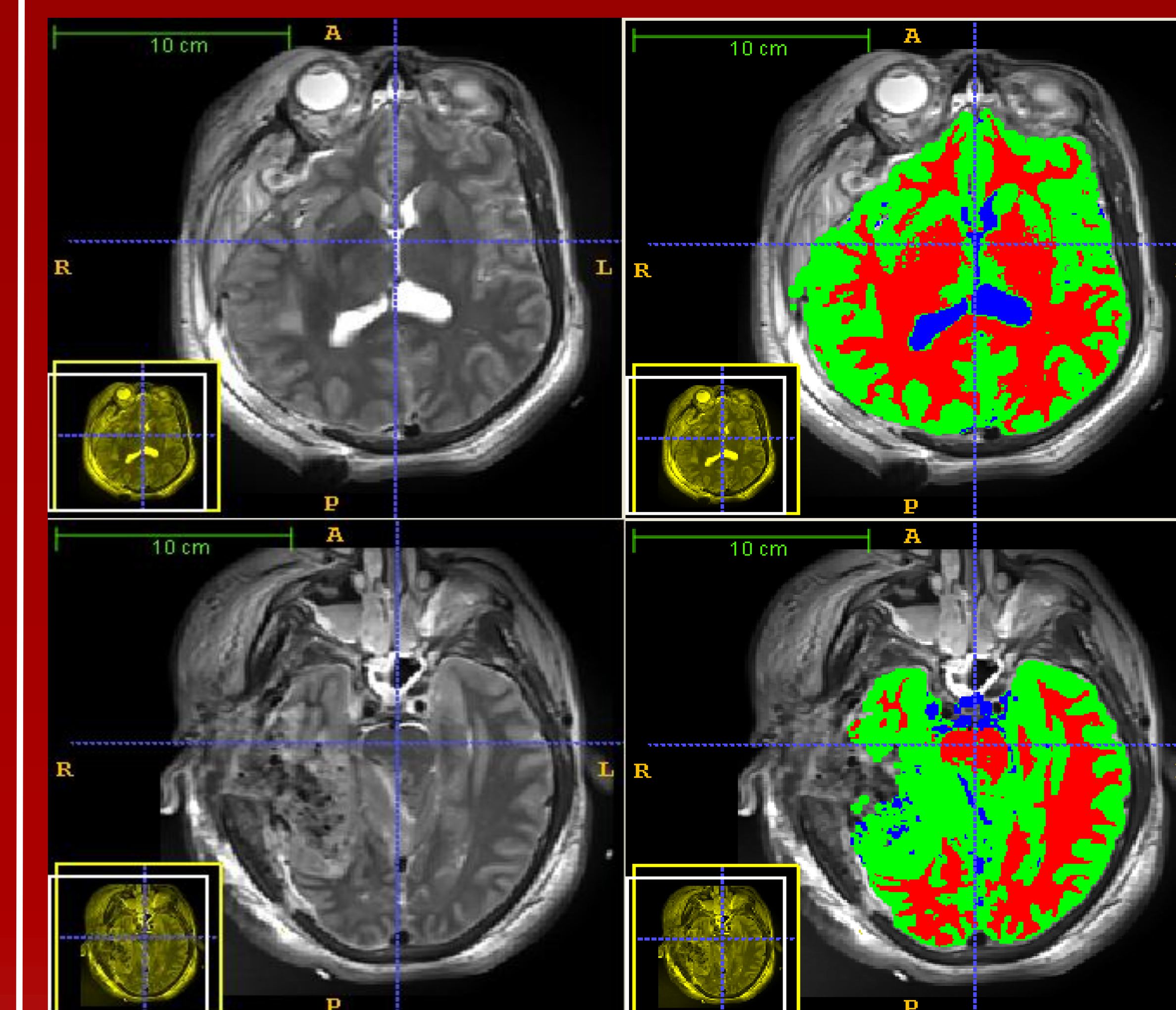

Figure 8. Use of ABC segmentation algorithm reveals the method's robustness to the presence of serious anatomical abnormality, as shown in this automatic segmentation of a TBI case.

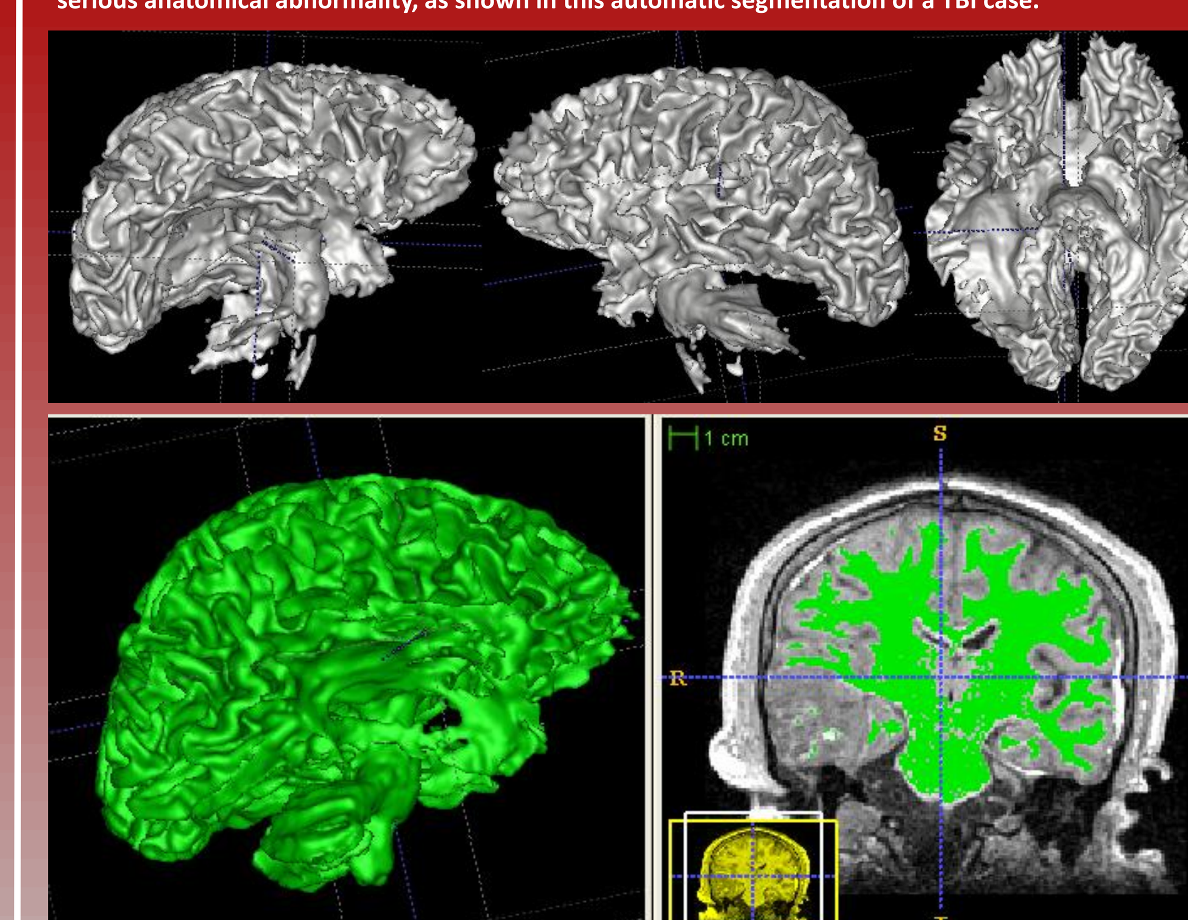

Figure 9. Brain tissue segmentation using ABC and Slicer displays the white matter surface with temporal lobe lesion.