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Three Dimensional Convolutional Neural Networks for Automated Lesions and Regions Segmentation in Rodents with Traumatic Brain Injury

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Background. Rodent models are essentials for studying the mechanisms and long-term consequences of traumatic brain injury (TBI). Magnetic resonance imaging (MRI) allows in vivo monitoring of structural brain changes; however, accurate segmentation remains challenging. Focal contusions can distort anatomy, hinder registration-based methods, and frequently necessitate manual correction. To address this, we developed a Convolutional Neural Networks (CNNs)-based tool to provide automatic and accurate 3D segmentations, enabling reliable volumetric analysis of rodent brain MRIs

Materials and methods. We employed data-efficient learning strategies and fine-tuning techniques to train the model on datasets of mice and rats subjected to contusional TBI by controlled cortical impact (CCI). The dataset consisted of 128 TBI and 86 sham mice (from C57BL/6J and CD1 strains), along with 5 Sprague-Dawley TBI rats for which the MRI scan was collected between 7 days and 8 months post-TBI. We evaluated the performance of the 3D multi-task CNN across mouse age, sex and strains, rodent species, times after injury, site of injury and MRI sequences (flash versus rare).

Results. Our 3D multi-task CNN integrates multi-scale inputs, deep supervision, and attention mechanisms, achieving a mean Dice score >0.98 for skull-stripping and >0.84 for lesion segmentation using five-fold cross-validation. Further, by exploiting densely annotated sham mice to guide learning on TBI subjects with fewer labeled regions, our learning strategy enabled segmentation of ten anatomical structures, including cortex, hippocampus, corpus callosum, and ventricles across hemispheres, with an average Dice score of 0.88. Lesion segmentation results showed high agreement with manual annotations (Pearson’s r = 0.974), with a 19% reduction in variability.

Conclusions. This automated approach improves consistency in segmenting anatomically distorted brain regions post-TBI and offers potential for standardizing analyses across studies, facilitating translational research.