BRAINMAP-NET: A Multilayer Convolutional Neural Network-Based Tool for Clustering Glioma Mechanical Subregions Using Topological Modeling of MRE-Derived Stiffness Gradients and Curvature

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Gliomas are the deadliest brain tumors with recurrence rates of up to 90%. Without an accurate map of the tumors' heterogeneity, surgeons operate with limited knowledge of tumor margins, often leaving malignant tissue that fuels recurrence. Conventional MRI reveals structural abnormalities but fails to capture the mechanical heterogeneity distinguishing tumor zones from healthy tissue, limiting surgical treatment precision. This study bridges that gap using Magnetic Resonance Elastography (MRE), a powerful imaging method that quantifies stiffness by tracking mechanical wave propagation through tissue. While MRE shows promise in differentiating tumor types, it is reduced to mean stiffness values that overlook spatial detail critical for understanding invasion. To address this, I developed BRAINMAP-NET, a convolutional neural network integrating topological modeling of MRE-derived stiffness gradients, Laplacian, and mean and Gaussian curvature to cluster distinct mechanical glioma subregions. Using MRE data from 24 glioma subjects, the model identified four biomechanical clusters with significant intercluster differences ($p<.001$). Cohen's d values for Laplacian features confirmed strong biomechanical separability ($|d|=7.5$), while mean curvature and stiffness yielded moderate-to-large effects ($d=0.47–0.93$). Gradient and damping ratio variations corresponded with tumor transition zones ($p<.005$). The CNN achieved 99.66% voxel-wise accuracy. These results reveal distinct mechanical phenotypes associated with proliferative cores, necrotic rims, and infiltrative edges, offering neurosurgeons a non-invasive framework for improving glioma resection precision. Future studies can create 3D-printed models utilizing BRAINMAP-NET, enabling surgeons to perform precise tumor resections.

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