3D Cerebranet++: State-of-the-Art 3D Structural Image Reconstruction Model for Breast Cancer Brain Metastasis: Attention-Guided 3D MRI Inpainting for Structural Reconstruction of Brain Tumor Regions via Composite Spatial-Frequency Optimization

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Breast cancer is the leading cause of cancer-related death among women, with approximately 42,000 deaths annually in the United States and over 700,000 worldwide. Brain metastases represent one of the most devastating complications, developing in 20-40% of patients with aggressive subtypes and contributing significantly to mortality in young women aged 20-49. Conventional MRI demonstrates limited sensitivity for sub-centimeter lesions and frequently produces blurred or poorly defined tumor margins. These edge ambiguities critically compromise stereotactic radiosurgery (SRS), where radiation dose is mapped directly to tumor boundaries and even sub-millimeter inaccuracies can result in neurocognitive decline or radiation necrosis. Despite this urgent clinical need, currently no reconstruction-based framework exists to restore tumor regions from surrounding brain context to improve volumetric edge clarity for radiation planning. This work introduces the first dedicated 3D structural reconstruction framework for breast cancer brain metastases (BCBM). This is the first model to perform full volumetric tumor inpainting in 3D MRI by reconstructing missing tumor regions from masked inputs using contextual brain anatomy and optimize tumor edge precision to support millimeter-level treatment planning. Our fully enhanced architecture 3D CerebraNet++ builds upon 3D UNett++ and demonstrates the highest baseline fidelity (PSNR 21.96, SSIM 0.5964, MSE 0.0086), incorporating attention-augmented dense skip connections, CBAM spatial attention, and deep supervision. Our work establishes a new benchmark for volumetric BCBM structural reconstruction and the first tumor-edge-aware 3D reconstruction framework in volumetric deep learning optimized for stereotactic radiosurgery precision.

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