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PET-Guided Machine Learning Refinement of MRI Tumor Boundaries without Manual Annotations

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Purpose

Accurate delineation of brain tumor margins is essential for neurosurgical and radiation therapy planning. Conventional MRI-based tumor segmentation can be limited by subjective margins and requires time-intensive manual annotation with a high degree of observer variability [1]. PET provides complementary metabolic information that can better highlight biologically active tumor tissue. However, PET data is not routinely integrated into boundary definition[2]. In this study, we present a weakly-supervised machine learning framework that utilizes PET uptake patterns to refine MRI-defined tumor boundaries without the use of any manual segmentations [3].

Materials and Methods

MRI and PET scans from a patient with a brain tumor were preprocessed using affine alignment, slice matching, and intensity normalization within an automatically derived brain mask. An initial MRI-based anatomic prior ("MRI_guess") was generated using intensity thresholding and morphological cleanup to approximate tumor extent. Metabolic pseudo-labels were derived from PET by defining PET_hot regions as the top 5%, 10%, or 15% of PET uptake within the brain, followed by connected-component filtering to isolate dominant hypermetabolic regions. These PET-derived pseudo-labels served as weak supervision for training a constrained random forest classifier using voxel-wise MRI intensity, PET intensity, and distance to the MRI prior as features. Model inference was restricted to a local search region surrounding the MRI prior to enforce anatomically plausible refinement. Performance was evaluated using metabolically driven metrics, including PET_hot inclusion, spillover into PET-cold tissue, and relative volume change compared to the MRI prior.

Results

Across PET_hot thresholds of 5–15%, the aforementioned method preserved metabolically active tumor regions while limiting non-metabolic expansion. Metabolic inclusion ranged from 0.924 to 0.992, indicating robust capture of PET_hot voxels. Spillover into PET-cold tissue decreased monotonically with increasing PET_hot threshold (0.224 at 5%, 0.157 at 10%, and 0.132 at 15%). The refined tumor volume scaled with PET_hot definition, with volume ratios relative to the MRI prior of 0.58, 0.79, and 0.96 for 5%, 10%, and 15% thresholds, respectively. The primary configuration (top 10% PET uptake) achieved high metabolic inclusion (0.992) with low spillover (0.157) while producing a smaller contour than the MRI. Overlay visualizations suggested refined contours that followed hypermetabolic tumor regions while remaining anatomically constrained.

Conclusion

This feasibility study demonstrates that PET-derived metabolic information can be used to weakly supervise machine learning–based refinement of MRI brain tumor boundaries without manual annotations. The proposed approach integrates multimodal imaging in a clinically interpretable manner, preserves metabolic tumor coverage, and reduces non-specific expansion. These early results warrant testing in larger patient groups with expert contours and may ultimately help refine targets for surgery and radiation.

References

[1] Castellano A, et al. Advanced Imaging Techniques for Radiotherapy Planning of Gliomas. Cancers. 2021;13(5):1063. doi: https://doi.org/10.3390/cancers13051063.
[2] Donche S, et al. The Path Toward PET-Guided Radiation Therapy for Glioblastoma in Laboratory Animals: A Mini Review. Frontiers in Medicine. 2019;6. doi: https://doi.org/10.3389/fmed.2019.00005.
[3] Frueh M, Fischer M, Schilling A, Gatidis S, Hepp T. Weakly supervised segmentation of tumor lesions in PET-CT hybrid imaging. Journal of Medical Imaging. 2021;8(05). doi: https://doi.org/10.1117/1.jmi.8.5.054003.

Figures

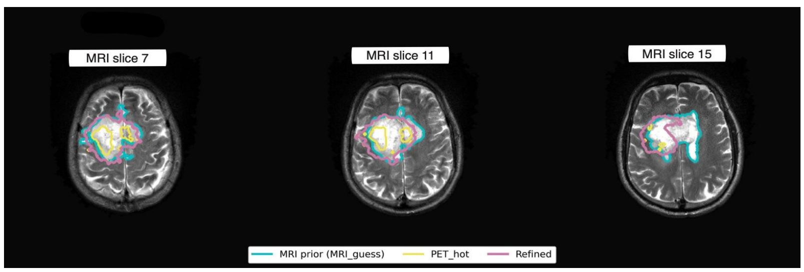

Figure 1: Axial T2-weighted MRI slices showing the MRI-derived anatomic prior (cyan), PET-defined hypermetabolic region (yellow), and final refined tumor contour (magenta).

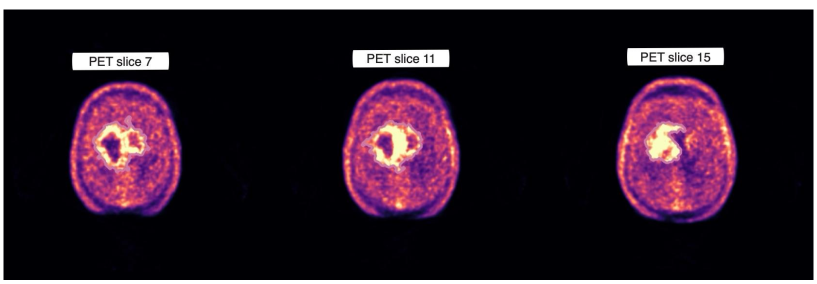

Figure 2: Axial PET slices with overlaid refined tumor contours (magenta) highlighting metabolically active tumor while minimizing spillover into surrounding brain tissue.

Table 1: Performance of PET-guided MRI tumor refinement across PET uptake thresholds

PET_hot Threshold (% of brain uptake)	PET Threshold (z-score)	PET_hot Brain Coverage (%)	Metabolic Inclusion	PET-cold Spillover	Volume Ratio (Refined / MRI Prior)
5%	1.582	3.5	0.986	0.224	0.581
10%	1.178	5.2	0.992	0.157	0.790
15%	0.976	7.0	0.924	0.132	0.964