PET-GUIDED MACHINE LEARNING REFINEMENT OF MRI TUMOR BOUNDARIES WITHOUT MANUAL ANNOTATIONS

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INTRODUCTION AND METHODS

INTRODUCTION

- Tumor margins are critical for surgery/RT planning
- MRI-only boundaries are subjective and usually require manual contouring
- PET highlights hypermetabolic (biologically active) tissue but is not routinely used for boundary definition
- Goal: weakly supervised ML to refine MRI tumor boundaries using PET uptake with no manual segmentations

METHODS

- **Data**: paired MRI + PET from 1 brain tumor patient.
- **Preprocessing**: affine registration, slice matching, intensity normalization, automatic brain mask
- **MRI prior (MRI_guess):** MRI intensity thresholding + morphological cleanup
- **PET pseudo-labels (weak supervision):**
  - PET_hot = top 5% / 10% / 15% uptake within brain mask
  - connected-component filtering to keep dominant hypermetabolic region(s)
- **Model:** constrained Random Forest (voxel-wise)
  - Features: MRI intensity, PET intensity, distance-to-MRI_guess
  - Inference restricted to a local region around MRI_guess (anatomic constraint)
- **Evaluation (metabolic metrics):**
  - PET_hot inclusion
  - spillover into PET-cold tissue
  - volume ratio vs MRI_guess

RESULTS

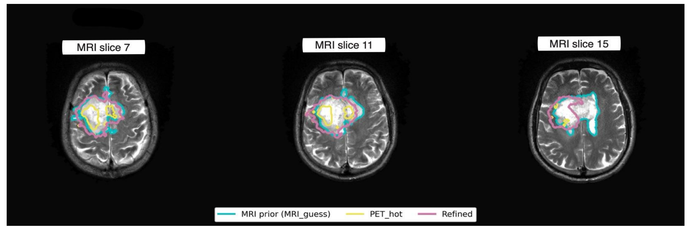

Figure 1: Axial T2-weighted MRI slices showing the MRI-derived anatomic prior (cyan), PET-defined hypermetabolic region (yellow), and final refined tumor contour (magenta).

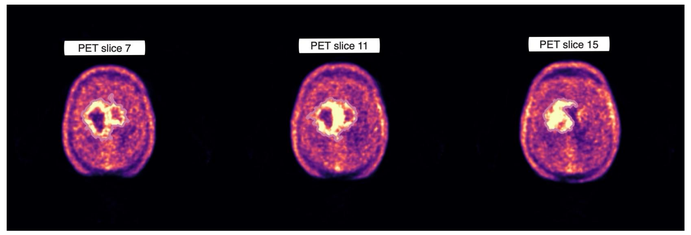

Figure 2: Axial PET slices with overlaid refined tumor contours (magenta) highlighting metabolically active tumor while minimizing spillover into surrounding brain tissue.

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

KEY FINDINGS

- **Overlay finding:** refined contour tracked PET-hypermetabolic region while staying confined to MRI-based prior region
- **Refinement behavior:** model mostly pruned ambiguous MRI margins rather than broadly expanding into surrounding brain
- **Threshold effect:** higher PET_hot thresholds produced larger (less pruned) contours with less PET-cold spillover

DISCUSSION & IMPACT

DISCUSSION

- **PET as weak supervision:** Using PET_hot regions as pseudo-labels provides a scalable way to guide boundary refinement without manual contours
- **Anatomy and biology balance:** The MRI_guess prior and local search constraint keep predictions anatomically plausible while PET drives the contour toward metabolically active tissue
- **Key limitations:** single-patient feasibility; no expert contours; PET noise/partial-volume effects and PET–MRI registration quality may affect pseudo-labels and refinement

CONCLUSION/

Key Demonstration

This feasibility study demonstrates that PET-derived metabolic information can weakly supervise machine learning-based refinement of MRI brain tumor boundaries without manual annotations.

Technical Achievement

The approach successfully integrates multimodal imaging (MRI + PET) in a clinically interpretable framework, preserving metabolic tumor coverage while reducing non-specific expansion.

Future Direction

These early results warrant testing in larger patient cohorts with expert contours and may ultimately help refine surgical and radiation therapy targets.

References:

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