# A Pilot Ambi-cranial PET System for GBM Surgery Guidance: Characterization and Analysis

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***Abstract*—Complete resection of gioblastoma multiforme (GBM) is currently impossible due to the coordinate misalignment between pre-operative imaging and surgical operation caused by brain shifts. Intraoperative radioguidance has the potential to provide real-time feedback about residual tumor to assist surgery. The current study investigates an ambi-cranial PET system to detect annihilation activity with an intracranial detector array attached to a probe and an extracranial arc array. This pilot study characterizes the unique system response and analyzes image reconstruction behavior. Measurement were simulated to account for attenuation, detector efficiency variation, accidental coincidence, scattering and counting noise. For the pilot study, the intracranial probe and extracranial arc arrays were assumed to be 22cm apart radially, with 2mm and 6mm detector sizes respectively. Considering radially symmetric geometry, a 22cm*4cm 2D region of interest (ROI) was simulated with 2mm isotropic voxel resolution. MLEM was used for pilot image reconstruction. Point activities were simulated at various locations within the ROI and then estimated from noisy simulation. Direct inspection of the ideal system matrix suggested inhomogeneous and isotropic system response. Reconstruction results conformed such observation: in particular, directional resolution along the radial direction degraded as the point source moved from the probe side towards the extracranial arc detector, with the full-width-half-max values varying from 2mm, comparable to the ROI voxel size, to 16mm, suggesting deteriorating in localization accuracy. On the other hand, tangential resolution is almost constant at approximately 2mm throughout the ROI, in concordance with radial symmetry. This particular pattern of spatial variation and anisotropicity coincides with the clinical desire to accurately identify activity close to cavity for surgical adjustment and high tangential resolution for intracranial radiotherapy.**

## I. INTRODUCTION

GLIOBASTOMA multiforme (GBM) is the most common and most aggressive malignant primary brain tumor in humans. GBMs are distinguished by extensive and diffuse infiltration of tumor cells into the dense network of interwoven neuronal and glial processes rendering these tumors extremely difficult to excise without large concomitant areas of normal brain. To best identify and excise tumor during the surgical operation, many image-guided systems have been introduced, such as a stereotactic navigation system (SNS) that combines a microscope with a tracking system and the use of pre-operative MRI images to relay the 3D location of the scalpel relative to the tumor and brain structures in real-time. However, both systems suffer from brain-shift during and following removal of the gross tumor mass. Intraoperative MRI systems are costly and require MRI-compatible surgical instruments. This project aims to develop a system to detect tumor and localize activity in the surgical frame of reference, known as *radioguided surgery* (RGS). Section II introduces the general notion of the ambi-cranial PET system under development and reports the simulation and image reconstruction procedures. Section III presents the analyzed system behavior and Section IV discusses their implications for clinical utility.

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## II. SYSTEM CONFIGURATION, SIMULATION AND IMAGE RECONSTRUCTION

### A. System configuration

Upon contrast injection, a probe with dual treatment and photon detection functionality will be inserted into the surgical cavity. In the exterior of the skull, an arc detector array covers the "opposite" side of the ROI in the extracranial space. The goal is to detect and estimate pair production activities in the ROI which resides between the probe and the skull, by identifying coincidence events detected by the probe and the arc detectors, as illustrated in Fig. 1

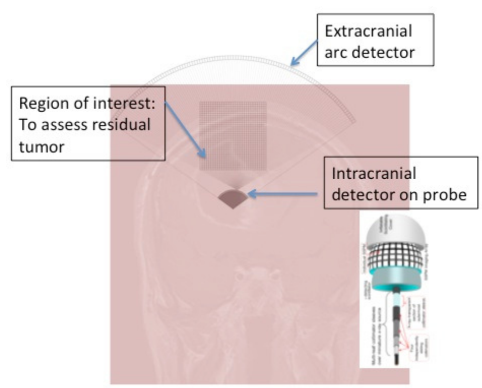



Fig. 1. Ambi-cranial PET system with intracranial probe detector array and extracranial arc detector array.

### B. Simulation process

- Simulation was configured in 2D plane. The probe and arc detectors were simulated by 20×2mm detector units and and 44×6mm detectors units respectively, and placed 220mm apart form each other along the radial direction. A region of interest of size 220mm×40mm was simulated where activity were to be estimated.
- The system matrix was generated with conventional geometrical Siddon ray-tracer (S-RT) method [1].
- An attenuation map was simulated to account for realistic absorption and scattering.
- Variation in detector efficiency was simulated to yield the nominal detected coincidence.

- The final measurement was simulated according to Poisson statistics based on the nominal detection counts.

The overall simulation follows [2]

$$Y_i \sim \text{Poisson}\left\{\sum_{j=1}^{p} a_{ij}\lambda_j^{true} + r_i + s_i\right\},$$

where $a_{ij} \geq 0$ is entry of the system matrix A incorporating scan geometry, attenuation, detector efficiency, etc. $\lambda_j^{true} \geq 0$ is the activity at voxel $j$; and $r_i \geq 0$ and $s_i \geq 0$ are the means of accidental coincidence events and scatters.

### *C. Reconstruction*

The maximum-likelihood expectation maximization algorithm [3] was used for image reconstruction.

## III. Results

The special asymmetric geometry of this system determines the unique system matrix. Sptial varying response are depicted in Fig. 2 and Fig. 3.

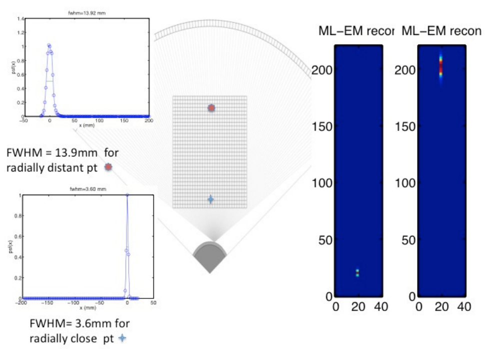



Fig. 2. Spatially-varying reconstruction properties.

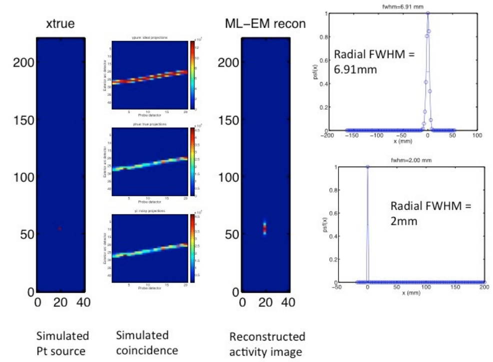
Table I quantitatively illustrates the general trend of decreasing spatial resolution as the estimation point moves away from the surgical cavity towards the exterior of the skull. These results suggest the following observations:

- Reconstruction is inhomogeneous and anisotropic.
- The directional resolution along the radial direction varies significantly. In particular, reconstruction closer to the probe detector enjoys superior resolution close to the voxel size, while activities closer to the exterior skull can only be reconstructed with low resolution along the radial direction.
- The directional resolution in the tangential direction is almost constant throughout the whole region of interest. By radial symmetry, it is reasonable to conjecture that the whole domain has uniformly high tangential resolution.

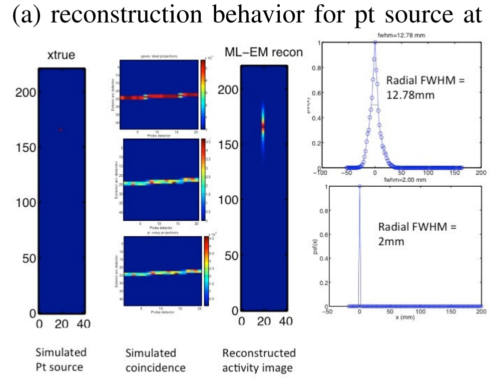
## IV. Discussion and conclusion

The goal of this work was to characterize the detection capability of the ambi-cranial PET system and assess its potential utility to detecting and localizing residual lesion in surgical excision procedure to remove GBM tumor, or to guide the radiotherapy beam on the probe towards the proper direction. Intriguingly, the specific pattern of spatial inhomogeneity and anisotropicity in reconstruction resolution aligns with such goals. In particular

- When the system is used to aid surgical resection of GBM lesion, the reconstruction result is used to inform the surgeon whether there are residual lesion tissue at the immediate vicinity of the surgical cavity where the mass tumor has been removed. In this case, accurately reconstructing near-field activity is of the utmost importance, which is satisfied by the good near-field reconstruction resolution as in Fig. 3(a). Moreover, as the surgeon incrementally remove more tissue and enlarge the cavity, the probe effectively *pushes* the cavity frontier towards the skull and changes the reconstruction coordinate. As a consequence, activity at the interior surface of the ROI adjacent to the surgical cavity can always be reconstructed with high resolution - providing information as to whether these regions should be further removed.
- When the intracranial probe operates as a radiotherapy unit, deciding irradiation direction is most critical. Fortu-




(a) reconstruction behavior for pt source at (54,20)mm




(b) reconstruction behavior for pt source at (164,20)mm

Fig. 3. Spatial varying point-spread-function from reconstruction

TABLE I
RECONSTRUCTION RESOLUTION AS A FUNCTION OF RADIAL DISTANCE FROM THE INTRACRANIAL PROBE.

| radial distance (mm) | radial FWHM | tangential FWHM |
|---|---|---|
| 6 | 2.17 | 2 |
| 20 | 3.6 | 2 |
| 74 | 6.91 | 2 |
| 100 | 10.56 | 2 |
| 120 | 9.84 | 2 |
| 140 | 13.67 | 2 |
| 164 | 12.78 | 2 |

nately, tangential resolution is uniformly high throughout the ROI, providing guidance for beam steering with high confidence.

In summary, this pilot simulation and image reconstruction study has revealed the unique detection and estimation characteristics of the ambi-cranial PET system under development. Preliminary results suggest the potential utility of this system to satisfy clinical needs for surgical guidance (both conventional and radiological), despite the low radial resolution in the far field. Upon further validation with higher resolution and alternative configuration parameters, results reported here will be used to design and construct the physical detectors .

To provide fast feedback in clinical environment and minimize imaging dose, reconstruction speedup utilizing ordered-subset [4] type technique and parallelization will be further investigated. To achieve good reconstruction under low-count statistics, proper incorporation of prior knowledge, such as tumor distribution from pre-operative MRI, will be studied.

## References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