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Towards Robotic SPECT for Parathyroid Imaging: A Simulation Framework for Optimizing a Dual Small-Field-of-View Detector Head

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Introduction

Compact handheld gamma cameras enable close-surface freehand single-photon emission computed tomography (fhSPECT), as demonstrated for parathyroid adenoma localization. Operator-driven acquisition however introduces reproducibility concerns. Robotic fhSPECT ensures systematic surface coverage, and extending to a dual-head configuration offers shorter acquisition times or reduced administered activity through complementary angular views per trajectory pass, albeit tighter workspace constraints. Yet the optimal dual-head configuration for this anatomically constrained application has not been studied. We present a simulation framework for evaluating dual small-field-of-view detector head configurations for robotic fhSPECT in parathyroid imaging with 99m-Tc-MIBI, generalizable to other detector configurations and fhSPECT applications.

Methods

Anonymized SPECT/CT data from three patients were used to compare dual small-field-of-view detector head configurations. Personalized robot trajectories were derived from patient CT surfaces, and Monte Carlo-based forward projections were simulated with added Poisson noise. MLEM reconstructions were evaluated to compare nine configurations: a single-head reference, seven fixed dual-head offsets ($\alpha = 0°–60°$ with 10° increments), and an active configuration where dual-heads vary the angular offset while following the trajectory. Submandibular glands and the parathyroid gland were evaluated per patient using centroid error, NCC, SSIM, and relative uptake ratios.

Results

All dual-head configurations outperformed the single-head reference across localization, image similarity, and uptake ratio metrics. Among fixed-offset configurations, $\alpha = 60°$ performed best for submandibular gland reconstruction and uptake ratio accuracy, while smaller offsets better preserved parathyroid localization. The active configuration performed best on the clinically relevant parathyroid target, with the lowest centroid error (1.0 mm), highest NCC (0.88), and lowest Submandibular/Parathyroid uptake ratio error (1.4%).

Conclusion

The active configuration represents the most promising acquisition strategy for robotic fhSPECT in parathyroid imaging. Results represent an upper bound under the matched-model condition, and the three-patient cohort limits generalizability. Phantom validation with the physical system is the next step toward clinical translation.

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