A Novel Method of Quantitative Planar Scintigraphy for Theranostic Applications—Experimental Validation and Clinical Evaluation

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INTRODUCTION

Post-therapy quantitative imaging is essential for dosimetry-guided precision cancer treatment in theranostics. Although SPECT is the typical choice for post-therapy quantification, its routine clinical use is constrained by scanner availability, acquisition time, and workflow complexity. To mitigate these limitations, we propose a novel method for quantitative planar scintigraphy that exploits the similarity in biodistribution between diagnostic radiotracers (typically PET-based) and their therapeutic counterparts. This study presents experimental phantom validation and preliminary clinical evaluation of the proposed approach.

METHODS AND MATERIALS

Rationale of quantitative planar scintigraphy in theranostic applications

For any organ inside a patient, its resulting counts on a planar image is proportional to its activity concentration, assuming that the counts predominantly come from the organ, i.e., there is minimal contribution of counts from another overlapping organ or tumor. If the ratio of an organ's planar counts relative to its activity concentration is known, one can derive the activity concentration using planar images with no need of SPECT scans, resulting in numerous benefits. The challenges is that this ratio is patient specific. The similarity in the activity distribution between pre-therapy PET and post-threapy scintigraphy, due to the unique rationale of theranostics, can be used to our advantage, i.e., to derive the ratio from simulations based on pre-therapy PET-CT study and to enable planar image based quantification.

Planar scintigraphy simulation

The key component of the proposed method, an in-house developed software library for simulation, consists of two parts. The first runs Monte-Carlo simulation from the input of pre-therapy diagnostic PET/CT and generates a phase space file describing the emitted gamma photons from the subject. The second, accounting for both characteristics of the gamma camera and acquisition parameters, converts the phase space file to an image matrix of pixel counts.

For routine clinical use, the computational time and the cost of the computational setup are two major factors affecting the feasibility of the method in clinical settings. This motivates the adoption of two acceleration approaches in the simulation software, including:

(1) The use of angular response function (ARF)—it precomputes the effect of a certain collimator and therefore obviates the need of computing the interactions of gamma photons with the lead speta, substantially reducing computation time. And

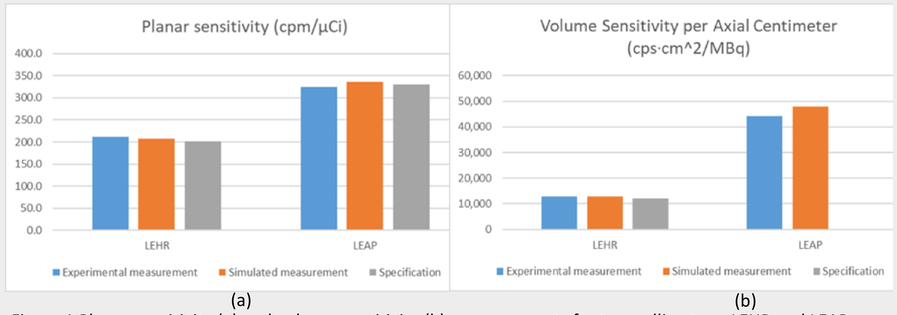
(2) GPU-based parallel computing—computations related to the interactions of gamma photons with the anatomy can be parallelized with the use of GPU, resulting in clinically feasible computation time with consumer-grade hardware.

Validation using experimental data

Experimental validation was performed using ^{99m}Tc-filled phantoms for the evaluation of planar sensitivity and volume sensitivity. The scans were performed on an Intevo SPECT/CT system (Siemens Healthineers) following NEMA protocols,

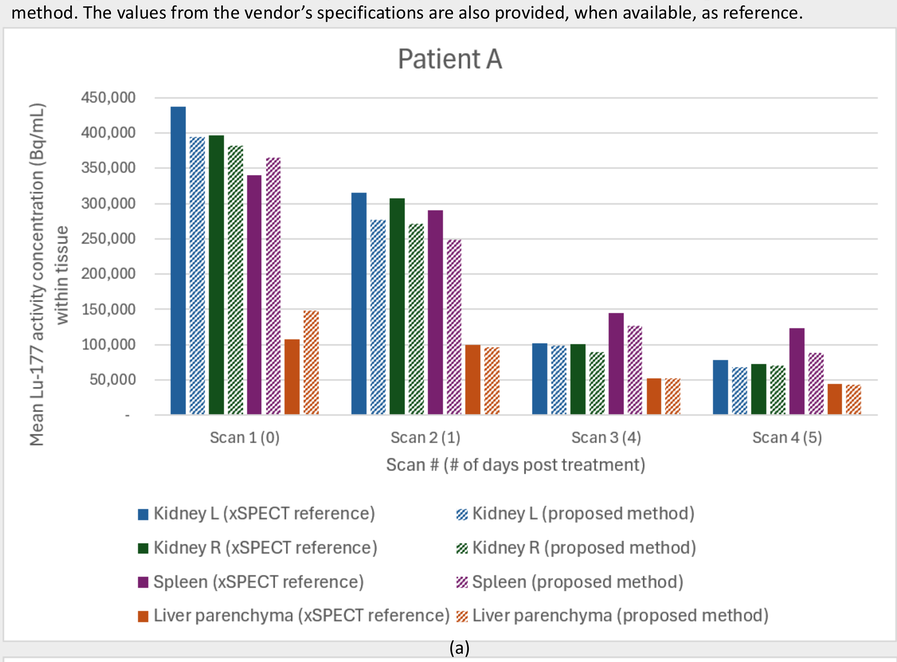
Evaluation using clinical datasets

For clinical evaluation, two anonymized datasets from patients treated with ^{177}Lu-DOTATATE, used in SNMMI's 2017 dosimetry grand challenge, were utilized. Estimated activity concentrations from planar images were compared with SPECT-derived reference values in a few organs across four post-therapy time points.

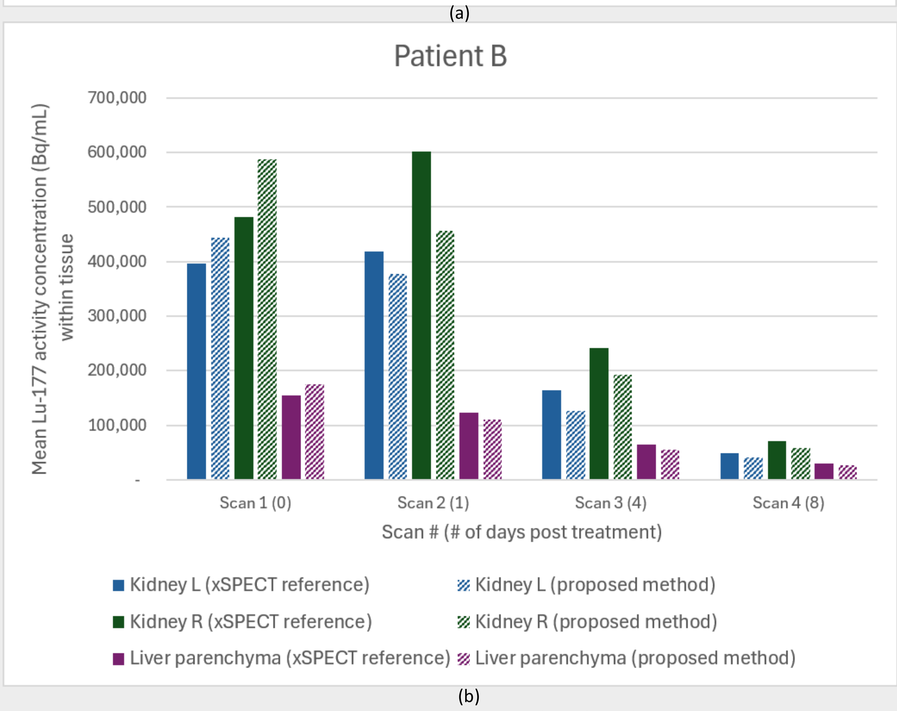


(a) (b)

Figure 1 Planar sensitivity (a) and volume sensitivity (b) measurements for two collimators, LEHR and LEAP, following NEMA standards from both experimental phantom scans and simulations using the proposed method. The values from the vendor's specifications are also provided, when available, as reference.



(a)



(b)

Figure 2 Mean Lu-177 activity concentrations within several organs both from the reference values based on xSPECT and by the proposed method, for patient A (a) and patient B (b).

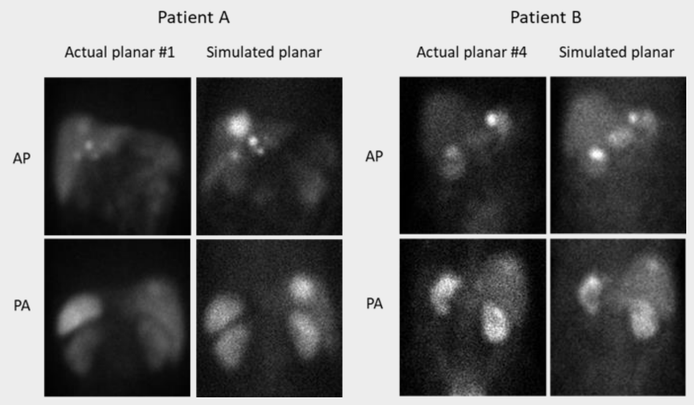


Figure 3 Both actual and simulated planar images for patients A (left, scan #1) and B (right, scan #4) for visual comparison. Both AP (top row) and PA (bottom row) views are included.

RESULTS

Figure 1 shows results of validation using experimental data. In phantom experiments, planar sensitivity and system volume sensitivity derived from simulated data agreed with experimental measurements within 10% for both LEHR and LEAP collimators.

Figure 2 shows evaluation using clinical datasets from SNMMI's 2017 dosimetry challenge. Differences between planar-based estimates and SPECT reference values were −7% ± 9% for patient A and −8% ± 15% for patient B, across all examined organs and time points.

Figure 3 shows both the actual and the simulated planar images from selected scans (scan #1 for patient A and scan #4 for patient B) for visual comparison. Reasonable agreement between the two sets of images is observed. Residual differences could be caused by the positional change in anatomy between the pre-therapy PET and post-therapy scintigraphic scan, since the simulated images are based on the former whereas the latter gives the actual planar images.

DISCUSSION

The proposed method of quantitative planar scintigraphy, if proven with acceptable accuracy, would provide a competitive means to implement patient dosimetry and to enable dose-guide precise treatment, due to the following:

- Whole body planar scintigraphy can be completed in 5-10 minutes, much faster than whole body SPECT performed on scintillator-based gamma cameras (30-60 minutes) and therefore better suited for implementing multiple time point patient dosimetry.
- Whole body planar scintigraphy can markedly increase patient access to dosimetry guided treatment and requires no investment high-end equipment (e.g., CZT cameras).
- With the effective use of some acceleration approaches, the method is capable of fast computation to meet clinical needs. While computation time varies with several factors, the clinical simulations in this work were done within approximately 30 minutes on a personal PC equipped with a consumer grade GPU.

A limitation of the proposed method is that its accuracy is affected by any overlapping tissues with substantial activity. This leads to challenges for tumor dosimetry, especially when the tumor is surrounded by organs with high levels of uptake. Organ dosimetry may be less affected and therefore more suitable applications of the proposed method.

CONCLUSIONS

The proposed method accurately reproduces planar imaging characteristics and demonstrates good preliminary agreement with SPECT-based quantification, supporting its feasibility as a practical alternative to SPECT for post-therapy quantitative imaging in theranostic applications.

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