Impact of ^{99m}Tc-MAA SPECT reconstruction methods on lung shunt and lesion/normal liver activity quantification in radioembolization

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Objectives

^{99m}Tc-MAA SPECT/CT can potentially be used for more accurate determination of lung shunt and for lesion/normal liver dosimetry based treatment planning in ^{90}Y radioembolization. Our goal is to determine optimal reconstruction methods/parameters for quantitative ^{99m}Tc-MAA SPECT/CT.

Methods

❑ Phantom for simulation and measurement

A digital equivalent liver/lung torso phantom with multiple spherical and ovoid shaped hepatic 'lesions' (14 to 30 mL) was used in a Monte Carlo simulation [1] study followed by measurement of the physical phantom on a Symbia SPECT/CT with typical clinic acquisition parameters. A clinically realistic activity distribution for ^{99m}Tc-MAA (200 MBq, a 5% lung shunt and a 5:1 lesion-to-normal-liver uptake ratio) was used. To assess visibility of extra-hepatic uptake, objects with very low activity concentration (0.01 to 0.1 MBq/mL) were placed in the 'cold' torso region of the phantom.

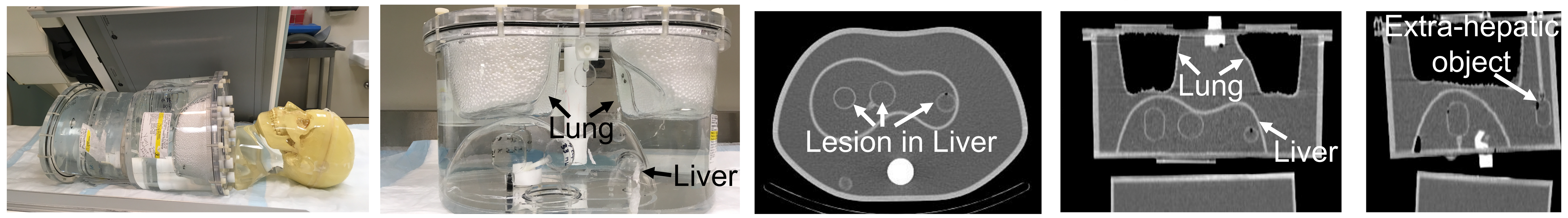

Fig. 1. Photographs and CTs of phantom used for simulation and experimental measurement. During SPECT/CT a 'cold' skull and elliptical phantom were placed adjacent to the liver/lung phantom to mimic scatter conditions during patient imaging. Monte Carlo simulation based projection data was also generated for this same phantom.

❑ Reconstruction methods

Simulated and measured phantom images were reconstructed with our in-house 3D-OSEM [2] without and with CT-based attenuation correction (AC), window based (5% lower window adjacent to 15% main window) scatter correction (SC) and depth-dependent collimator-detector response (RR).

❑ Evaluation

In the physical phantom study, reconstructions were evaluated by comparing error in lung shunt, lesion/normal liver activity quantification, visibility as well as noise in the background (normal liver). A liver relative calibration factor is used to convert counts to activity as this approach is commonly used in patient dosimetry studies [3].

$\cdot\, Activity\ Recovery_i = 100\% * {}^{A_i}/_{A_i^{True}}$ $\quad \cdot\, Noise_{BKG} = 100\% \frac{STD_{BKG}}{C_{BKG}}$ $\quad \cdot\, Visibility_i = (C_i - C_{BKG})/STD_{BKG} * \sqrt{N_i},$

where A_i , C_i, N_i and A_i^{True} are estimated activity, mean counts, number of voxels in the center slice and true activity for object i respectively. STD_{BKG} and C_{BKG} are standard deviation and the mean counts of background (normal liver for lesions, small sphere near extra-hepatic object for extra-hepatic objects.).

Simulation results

❑ Finding optimal scaling factor for scatter correction

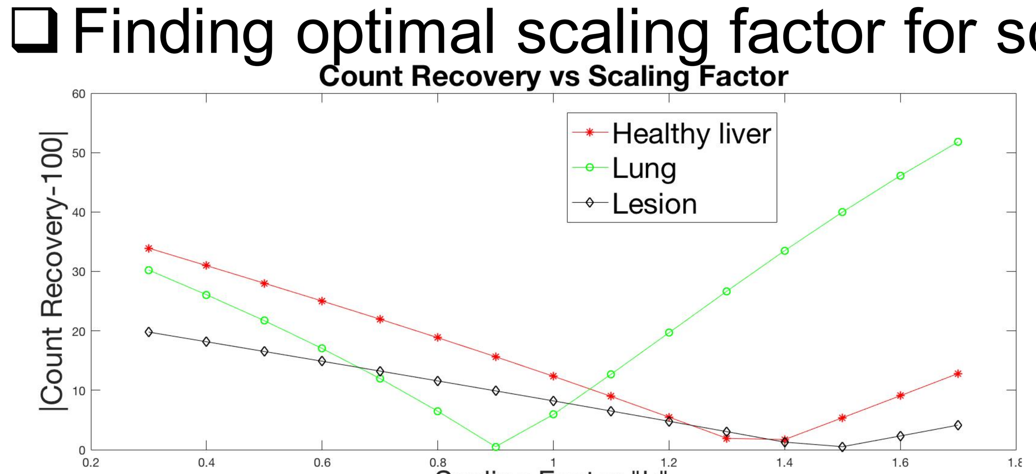

Fig. 2. For scatter correction, the optimal scaling factor k (typically assumed to be equal to one) of the scatter estimate S = k *(w_{main}/w_{low}) *0.5, was investigated [4] with the gold standard considered to be the 'primary' only reconstruction (ACRR) in the simulation study. Optimal k value (where count recovery = 100%) for accurate count recovery was 1.5 for lesions, 1.4 for normal liver and 0.9 for lung, but considering all regions in the optimization process, a value of k = 0.9 was selected as there is more gain in count recovery for lung than loss for lesion/normal liver when we set k = 0.9.

Measurement results

❑ Impact of corrections on image quality and quantification

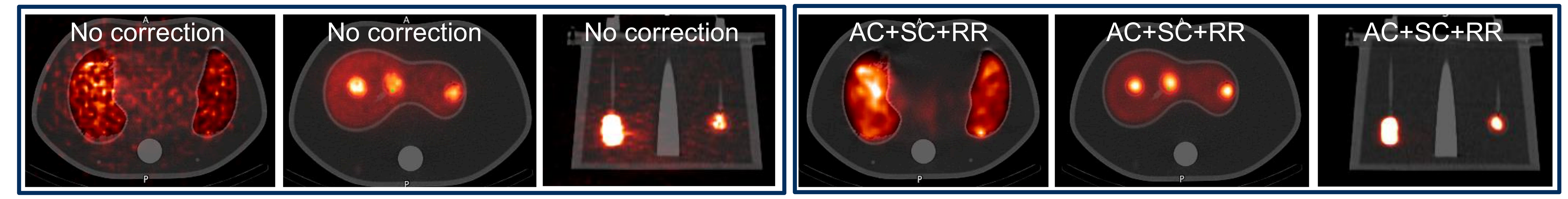

Fig. 3. Visual comparison between reconstructions with no correction and all corrections

	Scaling Factor for SC	Lung Shunt Error (%)	Activity Quantification Error (%)		Noise (%)	Visibility Index Average over objects
			Average over lesions	Normal Liver		
SPECT w/ No Correction		104.7	-30.2	11.2	19.8	137.3
SPECT w/ AC		7.1	-25.1	9.6	9.5	97.4
SPECT w/ SC	k = 0.9	73.1	-24.5	9.6	20.7	535.2
	k = 1.0	65.9	-23.6	9.3	20.9	734.7
SPECT w/ AC+SC	k = 0.9	-9.4	-20.0	8.1	10.0	433.7
	k = 1.0	-13.0	-19.2	7.8	10.1	595.7
SPECT w/ AS+SC+RR	k = 0.9	**-6.2**	-13.3	6.2	**7.9**	1041.1
	k = 1.0	-13.6	**-12.4**	**5.9**	8.2	**1621.5**

Table. 1. Comparisons were made at 40 EM equivalent iterations (5 iterations, 8 subsets). All reconstructions gave good quantification accuracy for the normal liver because of the liver relative calibration. Among correction methods, AC has biggest impact on the lung shunt accuracy and RR and SC on the quantification accuracy for lesions. Reconstruction with AC + SC + RR and a scatter scale factor of 0.9 gave quantification accuracy within 6% in lung and normal liver and 13% in lesions. Visibility of extrahepatic uptake was high for all methods but the index increased considerably with SC and RR.

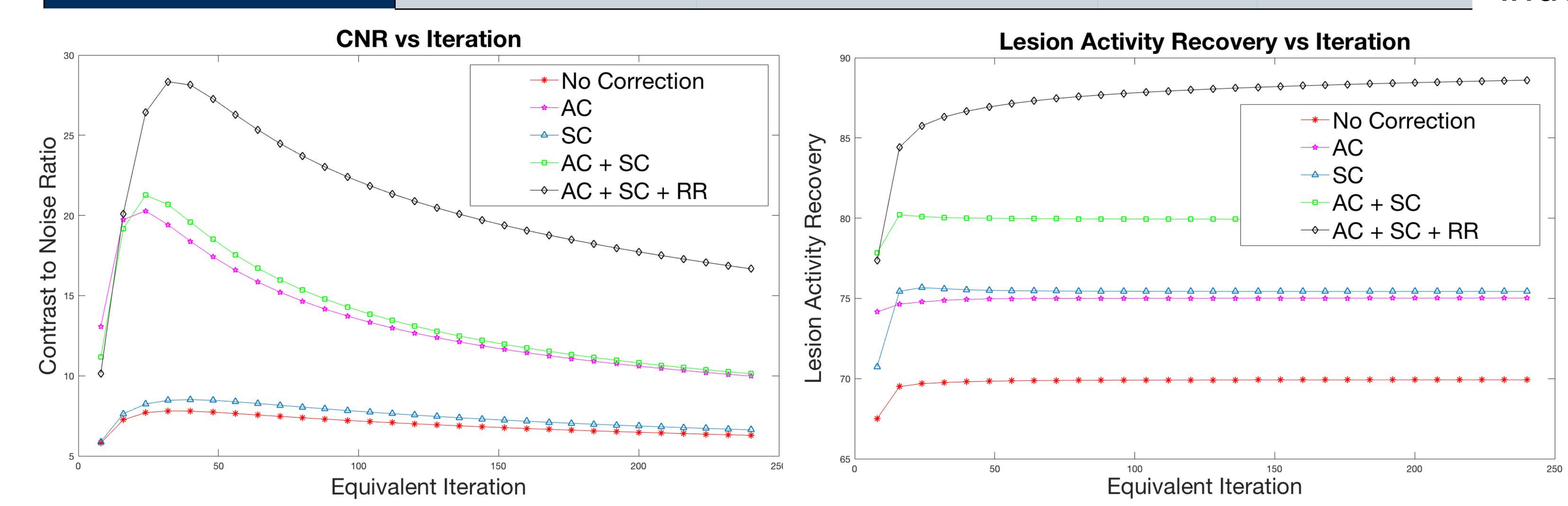

Fig. 4. Impact of increasing the number of iterations was also investigated. (Left) All Lesion contrast-to-noise curves reached maximum within ~30 iterations in all the reconstructions. (Right) Lesion activity recovery curves converged within ~30 iterations when resolution recovery is not included in the reconstruction while ~50 iterations are needed to approach convergence when resolution recovery is included.

❑ Correspondence to patient lung shunt calculations

	Lung Shunt (%)			
	Patient A	Patient B	Patient C	Phantom
Planar	13.6	17.1	4.2	
SPECT w/ No Correction	7.5	18.2	2.0	8.6
SPECT w/ AC	5.2	14.5	1.6	4.5
SPECT w/ AC+SC	4.1	12.8	1.0	3.7

* All reconstruction for patient data includes RR **clinic SC uses k=1

Table. 2. Tc-MAA planar and SPECT/CT imaging data for 3 patients were evaluated. Impact of reconstruction method on patient lung shunt has similar trend as in the phantom.

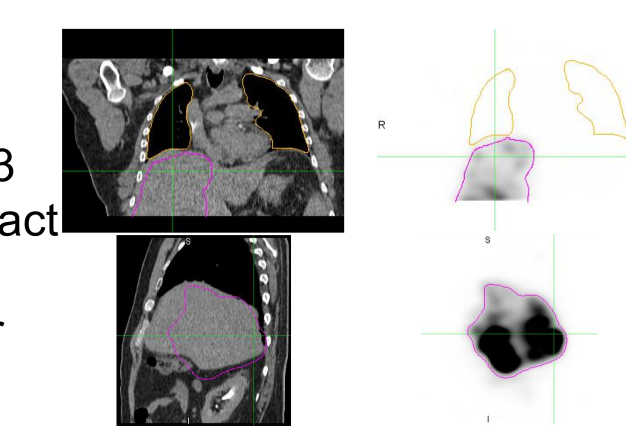

Fig. 5. CT image (left) and SPECT image (right) for a patient showing the liver and lung outlines used in the lung shunt calculation.

Conclusion

- Simulations showed that optimal scatter scaling factor was different for liver and lesions (1.4 - 1.5) vs lung (0.9).
- With relative calibration phantom measurement showed good quantification for normal liver with all methods, but corrections (AC+SC+RR) are needed to achieve high quantification accuracy in all regions including lung and lesions.
- Patient results for lung shunt showed similar trend as in phantom lung shunt calculation: underestimated without AC.

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Disclosure

Yuni Dewaraja is a consultant for MIM Software Inc., Cleveland, Ohio.

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