Update on HE vs UHE Collimation for Focal Total-activity Quantification in I-131 SPECT Using 3D OSEM

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Abstract*-- We calibrated a scintillation camera for the counts-to-activity conversion factor, CF, by measuring a phantom consisting of a sphere containing a known 131-I activity placed within an elliptical cylinder. Within a 3D OSEM reconstruction algorithm, we employed a depth-dependent detector-response model based on smooth fits to the point-source-response function. Using the ultra-high-energy (UHE) collimator and 100 iterations, the recovery coefficient, RC, appeared to be 1 for any sphere volume down to 20 cm3. The CF changed only a small amount as the background-over-target activity concentration ratio, b, increased for both UHE and high-energy (HE) collimation. Tests of activity quantification were carried out with an anthropomorphic phantom simulating a 100cm3 spherical tumor centrally located inferior to the lungs. With 3D OSEM reconstruction, using the global-average CF and no RC-based correction, mean bias in the simulated-tumor activity estimate over 20 realizations was -7.4% with UHE collimation, and –9.4% with HE collimation. For comparison, with 1D SAGE reconstruction, using the CF corresponding to the experimental estimate of b and RC-based correction, the mean bias was worse, -10.7% for UHE collimation, but better, -4.3%, for HE collimation.

I. Introduction

Our interest is in SPECT activity quantification of focal I-131 uptake within a volume of interest (VoI) to estimate total activity in tumors during radiopharmaceutical therapy. We employ a phantom-based calibration of the camera using a sphere with known activity in an elliptical phantom. The total counts within a spherical VoI in the reconstructed image yields the counts to-activity-conversion factor, CF, for a particular camera-collimator combination. The spherical VoI is drawn on the CT image and located in the SPECT image by a marker-based CT-SPECT registration. We had used a regularized 1D Space-Alternating Generalized EM (SAGE) algorithm with attenuation correction but without detector-response modeling [1], [2] for our previous patient imaging [3]. Since that work, we have been investigating the inherently-unregularized Ordered-Subset Expectation Maximization (OSEM) algorithm [4] with depth-dependent detector-response modeling [5] to improve image resolution. Those investigations have involved both an ultra-high-energy (UHE) collimator that was originally designed for gamma-camera positron imaging and the high-energy (HE) collimator that is usually used for I-131 imaging. The most significant I-131 gamma-ray emission is at 364keV (82%). However, emissions at 637keV (7.2%) and 723keV (1.8%) also exist and can penetrate the septa of the usual HE parallel-hole collimator. The UHE collimator has reduced septal penetration compared to the HE collimator [6].

We recently found that we needed to change our OSEM algorithm to handle edge effects in order to eliminate an artifact in patient reconstructions. The change also affected the phantom-based calibrations previously reported[7]-[8]. With the new version of the algorithm, the camera calibration results for the UHE collimator have been detailed in a separate manuscript submitted for publication [9]. In this paper, we summarize those results and present a comparison of the UHE calibration to that for the HE collimator. We also evaluate activity results from multiple realizations of a test phantom, with quantification based on OSEM for each collimator and compare those to quantifications based on SAGE for the same data.

II. Methods

To calibrate the Prism 3000 triple-headed gamma camera, SPECT images of a 200cm^3, known-I-131-activity sphere situated off center along the long axis in an elliptical water

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phantom were acquired into a 64x64 matrix. The sphere contained 14.5 MBq (391 μCi) of I-131. Uniform-background-activity level in the water was varied to produce four b values, ranging from 0 to 0.37. Here b is defined as the ratio of the activity concentration in the water of the cylinder divided by that in the water of the sphere. For the UHE collimator, we used a 120-degree circular-orbit with 6 degrees between projections and combined the data to get 360-degree data for a reconstruction. Each phantom acquisition was carried out at five values of the radius of rotation, R (19, 21, 23, 24.5 and 26cm). For the HE collimator, we used a 360-degree circular-orbit. In this summary, we preliminarily inferred the counts and conversion factor for the entire camera from the head 1 data alone (counts and CF from head 1 were simply multiplied by 3). A more accurate sum of the results from the 3 heads will be carried out later. Two R values (22 and 26cm) were investigated.

To model detector response for 3D OSEM reconstruction, we used experimental point-source measurements acquired for head 1 as a function of distance into a 512x512 matrix. For the UHE collimator, the average behavior of the point source response was modeled by a rotationally-symmetric Gaussian. Width and center location of the Gaussian were determined by non-linear least-squares fitting. For the HE collimator, a rotationally-symmetric single exponential was added to the Gaussian to model septal penetration. Due to the relative simplicity of the functions, and an assumption of shift invariance on a plane parallel to the detector, the detailed hole pattern was not taken into account.

Reconstruction was carried out with 1) SAGE using a shift-invariant strip integral system model (1D SAGE); 2) an OSEM algorithm driven by a 3D matrix, each slice of which was associated with a depth (3D OSEM). The change to the 3D OSEM algorithm was that edges of the volume were handled by assuming zero values outside the volume in the transverse (x-y) directions and repetition of the appropriate end slice in the + and - z-direction.

Monte-Carlo simulation [10]-[11] generated SPECT data for the UHE collimator to yield recovery coefficients for spherical volumes different than 200 cm^3. A matrix size of 64x64, and three different values of uniform background were investigated, but radius of rotation was not varied. The pixelated VoI was determined from the known location and radius of the simulated spherical activity.

As a test of the accuracy of the quantification scheme based on 3D OSEM compared to that based on 1D SAGE, a 100 cm^3 sphere containing 28.9 MBq (780 μCi) of I-131 and centrally located in an anthropomorphic lung phantom was sequentially imaged 20 times with each collimator. A 120 deg rotation was used with both collimators. For each collimator, the 3D OSEM CF was the global average of the CF's measured for the different R,b values. No correction for target volume was used. For 1D SAGE, the CF was chosen from a CF versus measured b curve; volume-dependent recovery-coefficient correction was invoked.

III. Results

Convergence was investigated on the basis of total counts within the VoI for the target sphere. Twenty iterations was previously sufficient for 1D SAGE, and was also found to be enough with 3D OSEM for the experimental data acquired with either the UHE or HE (Fig. 1).

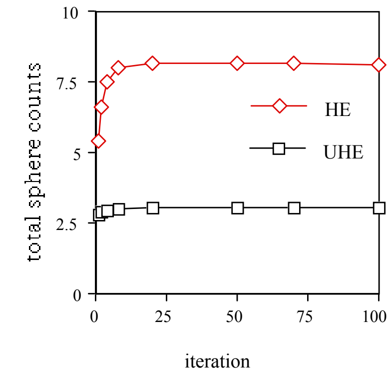

Fig. 1. Total-VoI-counts convergence for 200cm3 sphere. comparison of UHE versus HE. Thicker (x2) UHE septa cause lower efficiency (less counts).

The convergence for smaller spheres with Monte-Carlo simulation of UHE data was found to vary with the situation. In Monte-Carlo simulations, one hundred iterations provided sphere-activity estimates independent of the sphere volume as shown in Fig. 2 and therefore was used for 3D OSEM reconstructions of all UHE data.

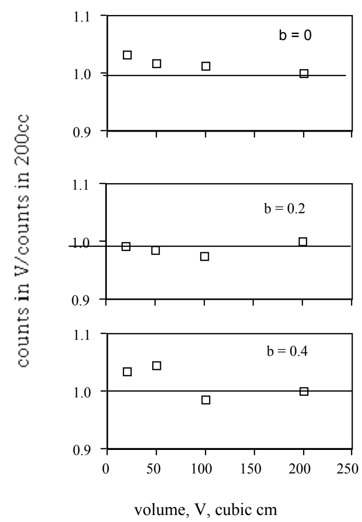

Fig. 2. Count ratio, small sphere over 200cc sphere, versus volume, V, of small sphere.

For the UHE collimator using 3D OSEM, CF varied linearly with b (Fig. 3). Units for CF are counts per (microcurie sec). The time in seconds is the total time of the acquisition. (This total time is the acquisition time for one stop times the number of stops. Moreover, it is further assumed that the data from all three camera heads contributes to the reconstruction.). With 1D SAGE, CF again exhibited a linear dependence on measured b for each R, but the absolute value of the slope was much larger than with 3D OSEM (for R = 23 cm, the absolute value of the slope was 2.67 times as large (0.310 divided by 0.116)). A sample dependence on b is shown in Fig. 3. At

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b=0, there are more counts with 3D OSEM due to superior resolution recovery (3D OSEM is inherently unregularized while 1D SAGE is regularized). With the largest background (b=0.37), count spill in from the background with 1D SAGE has brought the sphere count up to equal that with 3D OSEM. Results were similar at four other values of the radius of rotation, R.

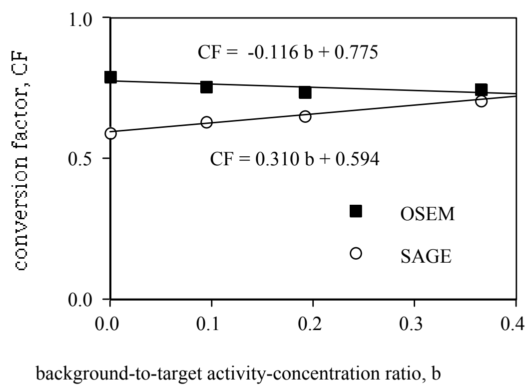

Fig. 3. CF versus b for the UHE collimator. R = 23cm.

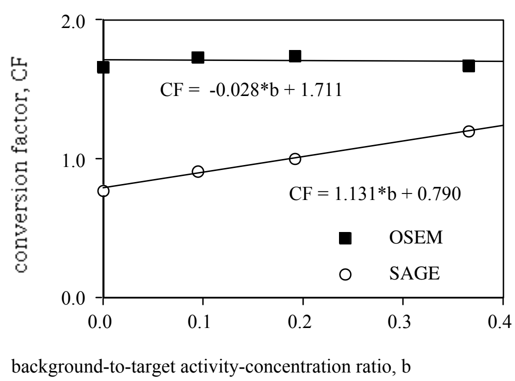

Fig. 4. CF versus b for the HE collimator. R = 22cm.

The equivalent plot with the HE collimator is shown in Figure 4. Note that with 3D OSEM the slope with the HE is much smaller than with the UHE. Also, for the HE the absolute value of the slope with 3D OSEM is much less than with 1D SAGE (0.028 compared to 1.131 at this radius). At the other measured radius of rotation the slope over intercept ratio with OSEM for HE collimation is similar to that for UHE collimation using OSEM. The change with radius for HE collimation isn't understood.

The bias in the activity estimate for the lung sphere is given in Table 1 below:

TABLE I. MEAN BIAS AND RELATIVE STANDARD DEVIATION OF THAT BIAS FOR HE AND UHE COLLIMATION AS A FUNCTION OF QUANTIFICATION METHOD.

Quantification method	UHE collimation		HE collimation	
	mean	Relative standard deviation	mean	Relative standard deviation
3D OSEM	-7.4%	5.9%	-9.4%	3.8%
1D SAGE	-10.7%	2.4%	-4.3%	7.4%

IV. DISCUSSION

The UHE collimator and 3D OSEM reconstruction appear to provide high resolution as judged by the good activity recovery for small spheres. This resolution should lessen spillover from background activity. The negative (rather than 0) slope for the UHE CF versus b curve is apparently an anomaly of how 3D OSEM reconstructs different activity distributions. With HE collimation, zero background and 3D OSEM, the total counts for the large sphere compared to the UHE result are more (a factor of 2.2, 1.711/0.790) than would be expected if both had only geometrically-collimated counts (a factor of 1.6 [6]) because 3D OSEM recovers septal-penetration counts present with the HE but not with the UHE. Imperfect recovery of such counts to the background region may explain why the CF doesn't decrease as much with b for HE collimation at R=22cm, compared to the "natural" decrease shown by the UHE collimation (that is, imperfectly-recovered septal-penetration counts from the increasing background increment the sphere total for the HE). Alternatively, the result may again be a characteristic of 3D OSEM reconstruction. In any case, quantification of focal total activity is better than 10% with both collimators and 3D OSEM. The bias is less with 3D OSEM than with 1D SAGE-based activity quantification for the UHE collimation but not for HE collimation. The noise, as measured by the relative standard deviation of the bias, is greater with 3D OSEM than with 1D SAGE-based activity quantification for the UHE collimation but not for HE collimation. The testing of more anthropomorphic-phantom geometries is needed to further compare activity quantification using UHE collimation versus that using HE collimation. So far, the results are similar.

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