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Image Reconstruction for a Partially Collimated Whole Body PET Scanner

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Abstract

Partially collimated PET systems have less collimation than conventional 2-D systems and have been shown to offer count rate improvements over 2-D and 3-D systems. Despite this potential, previous efforts have not established image-based improvements with partial collimation and have not customized the reconstruction method for partially collimated data. This work presents an image reconstruction method tailored for partially collimated data. Simulated and measured sensitivity patterns are presented and provide a basis for modification of a fully 3-D reconstruction technique. The proposed method uses a measured normalization correction term to account for the unique sensitivity to true events. This work also proposes a modified scatter correction based on simulated data. Measured image quality data supports the use of the normalization correction term for true events, and suggests that the modified scatter correction is unnecessary.

Index Terms

Collimation; fully 3-D PET; normalization; scatter estimation; septa; 2.5D

I. Introduction

The relative tradeoffs between 2-D and fully 3-D data acquisition are well documented and have been the source of ongoing debate in PET instrumentation for many years [1]–[3]. Originally, positron emission tomography (PET) systems acquired data in a “2-D” mode with collimation between each ring of detectors. Fully-3-D data acquisition, in which no collimation is present, offers the benefit of increased sensitivity to true events at the penalty of increased sensitivity to scattered and random events [4], [5]. Recent studies have explored the use of partially collimated systems, which use less collimation than 2-D mode, in order to optimize the tradeoffs between the two acquisition modes [6]–[8]. The goal of this work is to develop an image reconstruction technique for these partial collimation geometries.

Collimation optimization is well researched for SPECT systems [9]–[11], while only a few groups have studied unique collimation schemes for PET systems. Schmitz *et al.* have established with simulation results that scanners with every other septum removed can offer as much as 45% noise equivalent count rate (NEC) gains over 2-D and 3-D mode in common

clinical activity ranges [8]. MacDonald *et al.* in a follow-up study presented measured results that show roughly 30% NEC gains over 2-D and 3-D in an actual system with two out of every three septa removed [7]. Likewise, Qi *et al.* simulated multiple sparse collimation schemes for a prostate scanner and showed NEC and signal-to-noise improvements [12] over 2-D and 3-D mode for several schemes. For a brain imaging system, Aykac *et al.* used simulations to support an NEC improvement with a partially collimated system [6], although further work by this group was unable to translate the NEC improvement to image-based improved detectability with empirical data [13]. One potential reason for the lack of improvement is that they did not customize the data corrections and reconstruction for partially collimated data.

This work presents a novel detection normalization technique and scatter correction tailored for fully 3-D formatted data (all possible lines of response) acquired with partial collimation. Previous image based analyses for partial collimation did not customize the detector efficiency/normalization correction [14], [13]. Hasegawa *et al.* performed initial simulation studies to develop scatter corrections for various collimation designs, but did not propose a comprehensive data correction scheme or method to realize the potential of all of the oblique lines of response [15]. The goal of this work is to reconstruct artifact-free images from measured partially collimated data using all available lines of response. Our work presents a) sensitivity patterns for true events generated by analytic and Monte Carlo simulations, b) sensitivity for scatter events generated through Monte Carlo simulations, and c) a sensitivity correction technique applied to measured data.

II. Methods

We performed analytic and Monte Carlo simulations of and acquired measured data from the GE Discovery STE PET/CT scanner [16]. The scanner consists of 24 rings of BGO detectors with a radius of 43 cm (imaging field of view radius = 35 cm), axial length of 15.52 cm, and tungsten septa of length 5.4 cm and thickness 0.8 mm. We use the naming convention from [8] in which **2-D** designates a septa placed between each ring of detectors, **2.5D** designates septa positioned between every other ring, **2.7D** designates septa positioned between every three rings, and **3-D** designates no septa. Fig. 1 displays the septa placement. All septa variations discussed in this work have equal length, equal thickness, and azimuthal symmetry. The projection data will be presented as $Y(s, \varphi, r_1, r_2)$ which defines the line of response at radial position s , azimuthal angle φ , and that intersects detection rings r_1 and r_2 as shown in Fig. 2.

The “analytic” simulations calculated the average septa attenuation for each tube of response connecting each combination of detectors. The simulation subdivided each detector location in 15 smaller sub-samples and traced all possible lines of response between a pair of detectors’ sub-samples. The simulation analytically calculated the septa intersection and then the expected attenuation due to septa (based tungsten’s linear attenuation of 511 keV photons) for each sub-sampled line of response. The average of the septa attenuation across all the sub-sampled lines of response led to the septa attenuation between each detector pair. The inverse of the septa attenuation provides a noise-free estimate of the sensitivity to true events.

The Monte Carlo simulations used the photon tracking package SimSET [17] with an accurate model of the collimator assembly and a model of the detectors as a solid annulus of BGO. The 2-D, 2.5D, and 2.7D collimation schemes were modeled with the same basic collimator design (thin walled enclosure to hold septa in place), but with different septa configurations.

The measured data were acquired in 3-D format (collected all fully 3-D lines of response) with 2.7D collimators in position. The 2.7D acquisition required the removal of the standard 2-D collimators and the installation of custom 2.7D collimation.

We assessed the image quality (IQ) of the proposed algorithm with the NEMA-2001 IQ phantom [18]. With the standard phantom of 4 hot spheres, 2 cold spheres, and a cylindrical lung insert, we imaged the phantom 1) positioned in the center of the scanner for 20 minutes and 2) elevated to the edge of the transaxial field of view for 10 minutes.

III. Sensitivity to True Events

Figs. 3 and 4 present sensitivity patterns for true events generated from analytic and Monte Carlo simulations. These plots present the number of true events normalized to maximum value 1 detected from a 60 cm diameter uniform activity cylinder positioned in the center of the FOV. They represent the relative sensitivity of oblique planes that intersect detector rings as defined by

$$\bar{Y}(r_1, r_2) = \sum_{\varphi=1}^{\Phi} Y_{\text{Normalized Trues}}(s=0, \varphi, r_1, r_2) / \Phi \quad (1)$$

where φ is the number of azimuthal angles. The diagonal entries are from direct planes and off-diagonal entries are from increasing oblique planes. For example, in 2-D mode, direct planes are very sensitive to true events and oblique planes are less sensitive as shown in the diagonal band in the Fig. 3 2-D plot. The partial collimation plots have checkered patterns from shadow regions next to septa and the 3-D plot appears blank revealing basically equal sensitivity for all planes because of the absence of septa (There is a faint diagonal band in 3-D because the system is slightly more sensitive to oblique planes that have a longer intersection with the cylinder).

The sensitivity also varies based on radial distance from center of FOV. For a fixed oblique plane, at larger radial distances the septa are effectively longer than at the center of the plane, leading to a different septa intersection path length. Fig. 5 plots the radial sensitivity versus oblique plane sensitivity for all planes that intersect ring 5

($\bar{Y}(s, r_1) = \sum_{\varphi=1}^{\Phi} Y_{\text{Normalized Trues}}(s, \varphi, r_1, r_2=5) / \Phi$). All collimation types are most sensitive to direct planes, which in this figure is formed with planes that intersect ring 5 to ring 5. The sensitivity pattern dependence on oblique plane is evident in the reduced sensitivity for more oblique planes (e.g., ring 5 to ring 20) and reduced sensitivity for planes in the shadow of septa. Furthermore, the radial dependence is shown in the variations based on radial location.

IV. Sensitivity to Scattered Events

We tested the sensitivity to scattered events with Monte Carlo simulations of a 20 cm diameter, uniform activity, water-filled cylinder. In an effort to best utilize computation resources to accumulate relatively noise-free estimates of scatter patterns, we focused efforts on only the 2.7D and 3-D geometries. Simulations of 20 billion decays for each geometry were performed and single scattered events and multiple scattered events ($1 < \text{scatters} < 26$) were stored in a fully 3-D data format. These simulations required over 2300 CPU hours (1 GHz PowerPC G4 with 1 GB RAM) with importance sampling enabled in SimSET.

Figs. 6 and 7 present the sum of the detected single and multiple scatter events in each plane for a 2.7D and 3-D scanner. There is no evident structure to the 3-D single scatter events and the 2.7D and 3-D multiple scatter events. The 2.7D single scatter events have a pattern which is similar to the true sensitivity pattern with repeating blocks every three rings, but the variability between planes is at most a factor of 2 in the single scatter pattern as opposed to 100× variations amongst planes in the true event pattern. The single scatter pattern varies smoothly with at most 25% variations between neighboring planes. In 3-D mode, the collimator

assembly is retracted to one side of the scanner, which results in a different shielding on one side, leading to a slight asymmetry in the 3-D patterns between the front and the back of the scanner (ring₁ = ring₂ = 0 versus = 24).

V. Sensitivity Correction

A. True Sensitivity Correction

For fully 3-D scanners, true sensitivity correction factors, or detector normalization coefficients, are derived from variants of component-based variance reduction methods [19], [20]. In an effort to improve statistical accuracy with relatively short calibration scans, these methods model normalization terms as the product of individual crystal efficiencies and geometric factors, which account for variations in the detection efficiencies of lines of response. We propose a modification of the current component-based normalization correction on the GE Discovery DSTE. The current correction calculates the normalization factor for the line connecting crystal, c_1 , from ring, r_1 , with crystal, c_2 , from ring, r_2 , as

$$N_{c_1 c_2 r_1 r_2} = W \varepsilon_{c_1 r_1} \varepsilon_{c_2 r_2} g(s, \varphi \bmod B) \quad (2)$$

where

- W is a global scale term to define absolute units;
- $\varepsilon_{c_1 r_1} \varepsilon_{c_2 r_2}$ are individual crystal efficiencies;
- $g(s, \varphi \bmod B)$ is the geometric correction factor unique for each radial location and crystal location along the B transaxial crystals in one detector block.

The current geometric factor corrects for block edge effects within transaxial planes and assumes these factors are constant from plane to plane. Unbiased estimates of these factors are derived from taking the geometric mean of symmetric lines of response from the acquisition of a rotating rod source [21].

The crystal efficiencies and global scale term are derived from a blank scan and a relatively short acquisition of a uniform activity 20 cm cylinder. The factors are formed from a 3-D fan sum of all LOR's intersecting a crystal.

We propose the addition of a geometric factor to account for oblique plane-to-plane sensitivity variations. This factor $\hat{g}(s, r_1, r_2)$, dependent on radial location s and oblique plane, is used to form the proposed 2.7D normalization factor

$$\hat{N}_{c_1 c_2 r_1 r_2} = N_{c_1 c_2 r_1 r_2} \hat{g}(s, r_1, r_2). \quad (3)$$

Ideally, we would like to be able to derive $\hat{g}$ from one of the current normalization calibration acquisitions. The measurement of $\hat{g}$ could be performed with the current ^{68}Ge rotating rod source, which could adequately sample all radial locations. However, this would make the accuracy of the plane-to-plane values dependent on the axial uniformity of the rod source, which may not be guaranteed to be sufficient for this task. And, this acquisition would need to be very long to have sufficient counts to calculate precise plane-to-plane variations. The uniform cylinder used for detector efficiency calculation could be used to adjust for plane-to-plane variations. Unfortunately, these measurements do not adequately sample sensitivity at all radial locations; A 20 cm cylinder only covers 29% of the 70 cm transaxial field of view. To measure sensitivity dependent on radial location and oblique plane, we measured a uniform sheet source ($54 \times 41 \times 1.3$ cm) which covers 75% of the transaxial field of view and all of the axial field of view.

The proposed normalization factor was measured with the following steps under the assumption that a 2.7D system would have a fixed, non-retractable collimator. With the 2.7D collimators in position, we performed the current normalization calibration:

1. acquired data from rotating rod source data and derived $g(s, \varphi \bmod B)$;
2. acquired data from 20 cm uniform activity cylinder and derived ε^* and W .

These components formed $N_{c_1 c_2 r_1 r_2}$ which will be used in the next step and during our reconstruction analysis to show that the current normalization approach leads to images with artifacts due to improper normalization.

Next, we acquired fully 3-D formatted data of the sheet source filled with $0.7 \mu\text{Ci/cc}$ of ^{18}F for 20 minutes. We corrected the data for detector efficiency with the current normalization factors, $N_{c_1 c_2 r_1 r_2}$. We averaged over the 20 azimuthal angles orthogonal to the sheet source and applied attenuation correction to remove the slight influence of the bed. Then, we removed the effect of variable line of response path lengths through the sheet (oblique planes have longer path length than direct planes). In order to remove noise from these sensitivity measurements and to determine correction factors for the remaining 25% of the radial bins, we fitted 1-D Gaussian functions to the radial bins for each oblique plane. The matrix of all these fitted functions was normalized to mean of 1.0 and formed into $\hat{g}(s, r_1, r_2)$.

The measured events along with the Gaussian fits for four oblique planes appear in Fig. 8. Note that the plane with ring difference of 3 (close to a direct plane) is more sensitive to events than oblique plane with ring difference 21. Furthermore, the radial dependence varies in a complex manner by oblique plane (plane 15 has different shape than plane 21). Fig. 9 presents $\hat{g}$ for all radial bins and oblique planes; to present the factors in one image, each oblique plane was assigned an index number with increasing number equivalent to increasing ring difference (i.e., the right half of the image contains the most oblique planes). It is worth noting that Tanaka *et al.* suggested a similar geometric plane-to-plane normalization modification for a 2-D/3-D rotating septa system [22], but their approach did not account for a radial dependence in the term and was measured with a rod source.

As with all component-based normalization techniques, the geometric terms, now both g and $\hat{g}$, will remain basically constant for the life of a scanner. The variations in individual crystal efficiencies over time can be accounted for with the relatively short uniform activity cylinder acquisition. There are certainly other methods for deriving the each component in our normalization term that have tradeoffs of computation time, scan time, and accuracy. Badawi *et al.* have prepared a thorough analysis of different approaches [23]. We developed the proposed method to be able to highlight the deficiencies in the current 3-D normalization scheme used with 2.7D collimation and then the benefit of an additional geometric factor. The purpose of this work is not to determine the optimal method for deriving normalization terms, but rather to present the key factors in a normalization correction to show that artifact-free images can be formed from a partially collimated geometry.

B. Scatter Sensitivity Correction

The scatter correction for partial collimation was derived with the Monte Carlo simulation results from Section IV. The fully 3-D scatter estimate for a given scan can be formed with the Ollinger model-based 3-D scatter correction method [24], [25]. Considering that multiple scatters in partial collimation are very similar to multiples in 3-D mode (as shown in Fig. 7), we only focused on variations in single scatter patterns. We used the ratio of 3-D detected single scatters to 2.7 D single scatters as a multiplicative correction of the 3-D scatter estimate and represented this correction as a normalization term $N_{\text{Scatter}}(s, r_1, r_2)$. As performed for the true sensitivity correction, we removed the noise in the correction factors by fitting Gaussians

to the radial bins of the scatter estimates before taking the ratio of 3-D to 2.7D scattered events. Fig. 10 shows the scatter sensitivity factors which are used to modify the fully 3-D scatter estimate.

This correction term is only an approximate approach considering the ratio terms were derived from simulations of a 20 cm cylinder and will be applied to all 2.7D studies regardless of activity distribution. This approximation may be acceptable since these factors are relatively small and the 2.7D scatter pattern is smoothly varying.

C. Application of Corrections

The sensitivity normalization factors were incorporated into a custom version of fully 3-D Ordered Subset Expectation Maximization (OSEM) [26]. The correction factors modified the system matrix and were applied inside the iteration loop. The update equation for the expectation maximization algorithm is

$$x_j^{n+1} = \frac{x_j^n}{\sum_{i=1}^M \tilde{P}_{ij}} \sum_{i=1}^M \tilde{P}_{ij} \frac{y_i}{\sum_{j=1}^N \tilde{P}_{ij} x_j^n + R_i + \tilde{S}_i} \quad (4)$$

where x is the image estimate of size N at iteration n formed by measurements, y , of size M . All of the additive corrections were applied within the loop represented by randoms R and scatter $\tilde{S}$. The proposed true sensitivity corrections modified the system matrix as

$$\tilde{P}_{i,j} = \frac{A_i P_{i,j}}{\hat{N}_i} \quad (5)$$

where $\mathbf{A}$ is the attenuation correction matrix, $\hat{N}$ is the proposed component-based normalization matrix, and $\mathbf{P}$ is the 3-D projector matrix. The proposed scatter modification led to the new scatter estimate

$$\tilde{S} = S / (\hat{N} N_{\text{Scatter}}) \quad (6)$$

where S is the fully 3-D scatter estimate derived from conventional model-based scatter estimation [25].

The randoms correction was derived from the detected singles rates as discussed by Stearns *et al.* [27]. Randoms for a given line of response depend on the coincidence timing window, the detection efficiency of each detector, and the singles count rate for each detector. The randoms should not need a unique partial collimation sensitivity correction. This method for randoms compensation could be improved in future work by forcing certain lines of response with anticipated poor trues-to-randoms ratios to zero to improve the effective NEC in the reconstruction.

In this work, we applied the corrections inside the iteration loop of OSEM in order to preserve the Poisson statistics of the measurements to better match the OSEM likelihood function. The proposed sensitivity corrections could also be applied directly to the data prior to reconstructing with an analytic or iterative algorithm. The scatter should be first “de-normalized” and subtracted from the measured data prior to applying the normalization for true events as discussed by Ollinger [28]. In this case, the pre-corrected data would be

$$\tilde{y} = \frac{\hat{N}}{A} (y - R - \tilde{S}). \quad (7)$$

VI. Image Reconstruction From Partially Collimated Data

To provide a sense of the image artifacts formed with partial collimation, we analytically simulated noise-free data from a 20 cm uniform activity cylinder. Fully 3-D formatted data, containing lines of response between every detector pair, were generated for 2-D, 2.5D, 2.7D, and 3-D collimation and reconstructed with fully 3-D OSEM. Fig. 11 presents images reconstructed from noise-free data. The last row shows that fully 3-D reconstruction works well with 3-D data. Conventional fully 3-D reconstruction does not perform well when septa are positioned in the field of view. The forward projection and backprojection operations of the fully 3-D algorithm have no knowledge of the septa patterns leading to major image artifacts.

With 2.7D collimation on the Discovery DSTE PET/CT, we acquired fully 3-D formatted data of the NEMA image quality phantom with the 4 smaller spheres filled with 4 to 1 tumor to background activity concentration. With the phantom positioned in the center of the transaxial field of view, Fig. 12(a) presents transaxial slices reconstructed with fully-3-D OSEM (4 iterations, 20 subsets, no post-filter). With the current normalization correction (N), there are circular artifacts similar to the artifacts shown in the analytic simulations in Fig. 11. The proposed sensitivity correction applied in the reconstruction resulted in artifact-free images [Fig. 12(b)]. Fig. 13 displays a coronal splash view of the different reconstruction methods revealing a clear slice to slice variation when no partial collimation correction is used. Fig. 14 presents a sagittal slice and a profile through the second smallest hot sphere. Applying the 2.7D correction improves the image uniformity (reducing the baseline noise in the profile) as well as increases the peak height of the profile through the hot sphere. The residual lung error for each slice is shown in Fig. 15.

We also imaged the phantom when elevated to the edge of the transaxial field of view as shown in the attenuation image in Fig. 16. This elevated position will further test the radial dependence of the correction methods. Fig. 17 displays a transaxial and coronal slice with and without the 2.7D correction methods. These images are formed with roughly 1/3 the counts as the centered study. The coronal images without the 2.7D correction do have characteristic streak artifacts which are resolved with the 2.7D true sensitivity correction. Fig. 18 plots the mean background levels for the elevated phantom. We positioned 12 6 cm radius ROI's in the background of each slice and calculated the mean and coefficient of variation across of the mean pixel values in each ROI for each slice. The 2.7D true sensitivity correction reduces the variation in background mean values from slice to slice, and the additional scatter sensitivity correction further reduces the overall variation of values within each slice.

In the elevated phantom, there is a slight non-uniformity in the edge of transaxial images. This is partially due to the error in the attenuation map in this region because the CT field of view is truncated leading to approximate PET attenuation correction values. This also reflects that the approximation of a Gaussian shape to extrapolate measured values to lines of response with extreme radial locations may underestimate the scanner sensitivity in these regions leading to slightly hyper-enhanced values. The coefficients of variation presented in Fig. 18 highlight that the non-uniformity in the corrected images is less than the uncorrected images.

VII. Discussion

The proposed corrections remove the partial collimation image artifacts and improve image quality. Data collected with 2.7D collimation result in images with slice to slice artifacts and clear transaxial artifacts when there are sufficient counts. The correction methods greatly reduce the average lung error (by 25%) and reduce the variability of the error from slice to

slice as shown in Fig. 15. Background within slice and slice-to-slice variation is markedly less with the corrections.

There are clear visual improvements using the proposed correction terms from the measured true sensitivity patterns. The addition of the proposed simulated scatter sensitivity correction results in no visual improvements over the use of just the true sensitivity pattern. This scatter correction is potentially limited for two reasons: a) it was derived from the Monte Carlo simulations of an approximate scanner model and b) it was derived from the scatter patterns of a 20 cm phantom with a different activity/attenuation distribution than the IQ phantom. The scatter correction could be improved with unique Monte Carlo generated scatter estimates for each imaged object or with an analytic approximation of the partially collimated scatter. The fully 3-D scatter estimate may be an acceptable scatter estimate for 2.7D reconstruction given that simulations showed scatter sensitivity is very similar between the 2 geometries and the true sensitivity only correction provides acceptable image quality.

The goal of this work was to present a method for artifact-free image reconstruction of partially collimated data, not to prove an image-based improvement over fully 3-D or 2-D data. The data collected in this study required the lengthy installation of custom collimators complicating the acquisition of 3-D, 2.7D, and 2-D data from the same phantom.

The proposed methods for deriving sensitivity correction factors are expected to be applicable to other partially collimated PET systems with different geometries. It is anticipated that the proposed trues geometric component, $\hat{g}$, and scatter modification N_{Scatter} will have more variability in systems with longer septa, thicker septa, or smaller bores. As with our proposed techniques, all systems containing partial collimators with azimuthal symmetry should have normalization terms with a dependence on radial location and oblique plane.

VIII. Conclusion

We have developed a successful method for reconstructing images from partially collimated data and demonstrated its performance with measured 2.7D data. The method uses a true sensitivity normalization term, derived from sheet source measurements, to modify the system matrix in a fully 3-D OSEM algorithm. The additional step of an approximate scatter compensation to modify the fully 3-D scatter estimate appears unnecessary, leading to mildly enhanced image quality. Past studies have shown that partially collimated systems provide better NEC performance than 2-D and 3-D systems; future work needs to use the proposed reconstruction algorithm to assess if these NEC gains can translate into measurable image-based improvements and clinical value.

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Fig. 1.
Placement of septa in partial collimation acquisition.

Fig. 2.

Geometry of cylindrical PET scanner. Transaxial view (left) displays sinogram variables s and ϕ defining line of response AB. Longitudinal section (right) shows that line AB intersects detector rings r_1 and r_2 . The x and y axis are rotated to illustrate all variables.

Fig. 3. Relative sensitivity patterns for different planes derived from analytic simulations. These plots display the average sensitivity to true events from a 60 cm diameter cylinder for each plane that intersects detector rings, ring₁ and ring₂. The 3-D plot is close to being fully saturated because all planes are almost equally sensitive.

Fig. 4. Relative sensitivity patterns for different planes derived from Monte Carlo simulations. These plots display the average sensitivity to true events from a 60 cm diameter cylinder for each plane that intersects 2 rings of scanner (ring₁ versus ring₂).

Fig. 5. Relative true sensitivity patterns for lines of response which intersect ring 5 at different radial locations versus different planes derived from analytic simulations.

Fig. 6.

Detected single scatter events derived from Monte Carlo simulations of 20 cm diameter cylinder for each plane in a 2.7D and 3-D system. The third column presents the ratio of 3-D to 2.7D sensitivity and offers approximate factors for modifying the 3-D scatter estimate for 2.7D scatter estimation.

Fig. 7. Detected multiple scattered events (photons have scattered 2 or more times) derived from Monte Carlo simulations of 20 cm diameter cylinder for each plane in a 2.7D and 3-D system.

Fig. 8.

Measured sheet source data from 2.7D collimation showing events for a fixed azimuthal angle for all radial bins. Four oblique planes which intersect direct plane 23 with ring difference +3, 9, 15, and 21 are presented along with fitted Gaussian functions. The fitted Gaussian functions for all planes in the scanner form $\hat{g}$.

Fig. 9. Plane-to-plane geometric correction factors ($\hat{g}(s, r_1, r_2)$) for 2.7D collimation derived from measured sheet source data. Factors are unique for each radial location and oblique plane.

Fig. 10. Scatter sensitivity correction factors (N_{scatter}) for 2.7D collimation derived from Monte Carlo simulations of 20 cm uniform cylinder.

Fig. 11. Transaxial slice (left) and coronal slice (right) from non-corrected fully 3-D OSEM reconstructions of analytically simulated noise-free 20 cm uniform cylinder. Each row contains images reconstructed from fully 3-D formatted data acquired with different septa configurations.

Fig. 12. Transaxial splash view of centered image quality phantom measured with 2.7D collimation. Conventional fully 3-D OSEM (A) resulted in circular artifacts highlighted with arrows and proposed fully 3-D OSEM with 2.7D true and scatter sensitivity correction does not contain visible artifacts(B).

Fig. 13. Coronal splash view (anterior to posterior) of the centered image quality phantom measured with 2.7D collimation. Figures A, B, C show images without a 2.7D correction, with 2.7D true sensitivity correction, and with 2.7D true and scatter sensitivity corrections. Conventional fully 3-D OSEM (A) resulted in axial non-uniformities.

Fig. 14.

Sagittal view of the centered image quality phantom measured with 2.7D collimation without 2.7D correction (A), with 2.7D true sensitivity correction (B), and with 2.7D true and scatter sensitivity correction (C). Right: Profile through the hot sphere as indicated by the dashed lines on the images at left.

Fig. 15. Residual lung error for image slices of the centered IQ phantom imaged with 2.7D collimation.

Fig. 16. Attenuation map of elevated IQ phantom formed from the transforming the CT attenuation correction image. The units in the colorbar refer to the linear attenuation coefficients (1/cm) at 511 keV.

Fig. 17.

Images of elevated IQ phantom with zoomed view of transaxial slice and coronal slice through second largest hot sphere and cold sphere. Figures A, B, C show images without a 2.7D correction, with 2.7D true sensitivity correction, and with 2.7D true and scatter sensitivity corrections.

Fig. 18. Mean background level and coefficient of variation in background levels for each transaxial slice of the elevated phantom.