Location-known-exactly human-observer ROC studies of attenuation and other corrections for SPECT lung imaging

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***Abstract*— We use receiver operating characteristic (ROC) analysis of a location-known-exactly (LKE) lesion detection task to compare the image quality of SPECT reconstruction with and without various combinations of attenuation correction (AC), scatter correction (SC) and resolution compensation (RC). Hybrid images were generated from Tc-99m labelled NeoTect clinical backgrounds into which Monte Carlo simulated solitary pulmonary nodule (SPN) lung lesions were added, then reconstructed using several strategies. Results from a human-observer study show that attenuation correction degrades SPN detection, while resolution correction improves SPN detection, even when the lesion location is known. This agrees with the results of a previous localization-response operating characteristic (LROC) study using the same images, indicating that location uncertainty is not the sole source of the changes in detection accuracy.**

***Index Terms*— SPECT, lung imaging, attenuation correction, lesion detection, ROC and LROC analysis**

I. Introduction

SEVERAL studies have suggested that using attenuation correction (AC) in PET reconstruction may reduce lesion contrast in some situations, and thus may hurt observer performance on lesion-detection tasks [1]–[4]. We have previously seen that attenuation correction reduces the performance of model and human observers performing a lesion search task—detecting a solitary pulmonary nodule (SPN) lung lesion in SPECT images—as measured by area under the localization-response operating characteristic (LROC) curve [5], [6]. This raises the question whether the attenuation correction interferes with the observer's ability to search the image by distracting attention to a non-lesion region, or is simply making the lesion less visible. Analysis using a model observer suggested the later [5].

In this paper we assess the impact of attenuation, resolution, and scatter corrections on lesion detection in SPECT reconstruction by having human observers perform a location-known-exactly (LKE) lesion detection task. Receiver operating characteristic (ROC) curves are used to compare image quality with and without attenuation correction. Area under the curve (AUC) is used as the figure of merit. We compare the human observer results with a model observer and with our earlier human-observer LROC study [6].

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TABLE I

Reconstruction algorithms under evaluation

code	algorithm description
FBP	filtered back projection, Butterworth postfilter
NC	RBI, no corrections, 0.46cm postfilter
RC	RBI, resolution correction, 0.46cm postfilter
ACh	RBI, attenuation correction, 3.38cm postfilter
ACl	RBI, attenuation correction, 0.46cm postfilter
ASC	RBI, attenuation + scatter correction, 0.46cm postfilter
AllC	all three corrections, 0.46cm postfilter

II. Methods

A. Data generation and image reconstruction

^{99m}Tc-labeled NeoTect® is a SPECT agent used to detect solitary pulmonary nodules [7]. Nine clinical NeoTect scans form the basis of this study. Lesion-absent images were formed by taking clinical data, adding noise using a parametric bootstrap, and then reconstructing as usual. Lesion-present images were created the same way, but with the addition of Monte Carlo simulated projections of 1-cm diameter spheres to the clinical background. The simulation does not account for attenuation by the lesion. This hybrid approach produces images with clinically realistic backgrounds, but with the certainty about lesion presence and location found in simulated images.

Seven reconstruction algorithms were tested. Table I summarizes the different reconstruction algorithms and gives the codes used to identify them in the figures. One was filtered back projection (FBP) with no corrections and a fifth-order 3-D Butterworth (0.20 pixel cutoff) post-reconstruction filter. The other six strategies used the Rescaled-Block-Iterative (RBI) algorithm with various corrections to compensate for degradation due to attenuation, scatter, and depth dependent resolution [5], [8], [9]. All iterative algorithms included Gaussian filtering after reconstruction. Figure 1 shows an example data set reconstructed using three of the iterative strategies, illustrating the potential for the lung lesion to merge with the mediastinum when attenuation correction is employed.

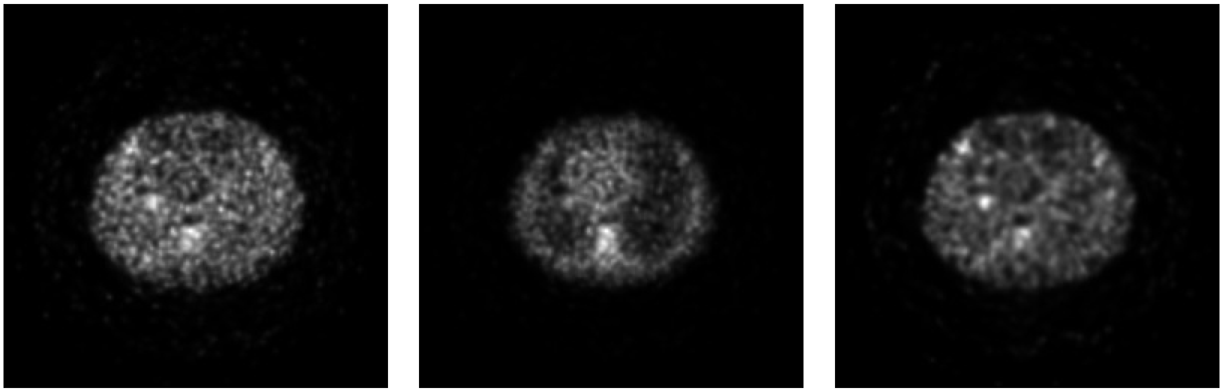

Fig. 1. Anecdotal reconstructions of one data set using three strategies. Note the lesion to the upper left of the spine is less visible in the attenuation-corrected (middle) image.

B. Observer study

Transverse slices at different levels were extracted from the 3-D reconstructions to produce the images used in the observer study. To predict human performance, a channelized nonprewhitening (CNPW) model observer [10] performed the lesion-detection task. Area under the ROC curve was computed using LABMRMC software from the University of Chicago.

Human performance on the lesion-detection task was measured by having three scientists in our medical physics group read each image. A cross hair superimposed on the image indicated the potential lesion location, eliminating search from the observer's task and making this an LKE detection task. The observers began by reading training sets of 108 images for each of the algorithms, receiving feedback on lesion presence after each image. After reading an image, the observer indicated how confident he was that a lesion is present at the indicated location. After completing training, each observer read two study sets of images per algorithm. A study set began with 54 retraining images, for which feedback was again provided, followed by 108 study images with no feedback. Half of the images contained one lesion, the other half no lesion. Areas under the ROC curves for each observer and algorithm were computed using LABMRMC. Observers read the sets in a random order.

A previously reported study had human observers (three nuclear-medicine physicians and two scientists in our medical physics group) perform a lesion search task with the same image sets [6]. Areas under the LROC curves were computed using Swensson's algorithm [11].

III. Results and Discussion

As part of the earlier LROC study we computed local contrast-recovery (CR) ratios for each of the algorithms [6]. These results are reproduced in figure 2. The CR for the attenuation-correction strategies is the same as, or larger, than that for strategies which do not include attenuation correction. The highest CR ratio, indicating the most quantitatively accurate reconstruction, is produced by incorporating using all corrections into the reconstruction algorithm.

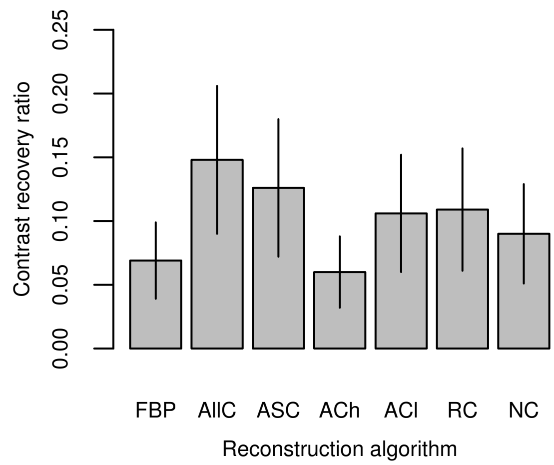

Fig. 2. Contrast recovery ratios for each algorithm. The center lines indicate error bars.

Figure 3 compares model-observer predictions of area under the ROC curve with the results of our LKE human-observer study for six of the reconstruction algorithms. The CNPW model observer predicted that attenuation correction would degrade lesion detection performance even when search is removed from the task. The human-observer results confirm this prediction. This shows that attenuation correction does not merely distract attention to other parts of the image, but actually makes the lesion harder to detect even when one knows its exact location.

The CNPW observer does not do a good job of predicting human performance reading images produced by FBP. This is not surprising, as a non-prewhitening model observer cannot compensate for the noise correlations introduced by FBP. Spearman's rank-correlation coefficient $r_s = 0.37$ when FBP is included. It rises to $r_s = 0.9$ when FBP is excluded. Because of the small number of points, neither is significant at the 0.05

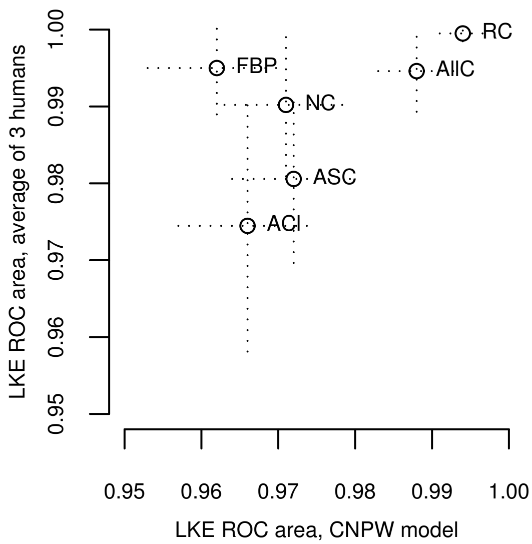

Fig. 3. Predicted area under the LKE ROC curve computed using the CNPW model plotted versus actual human observer performance on the LKE task. Dotted lines indicate error bars. Note general trend agreement between model and human observers, except for FBP which the model found more difficult.

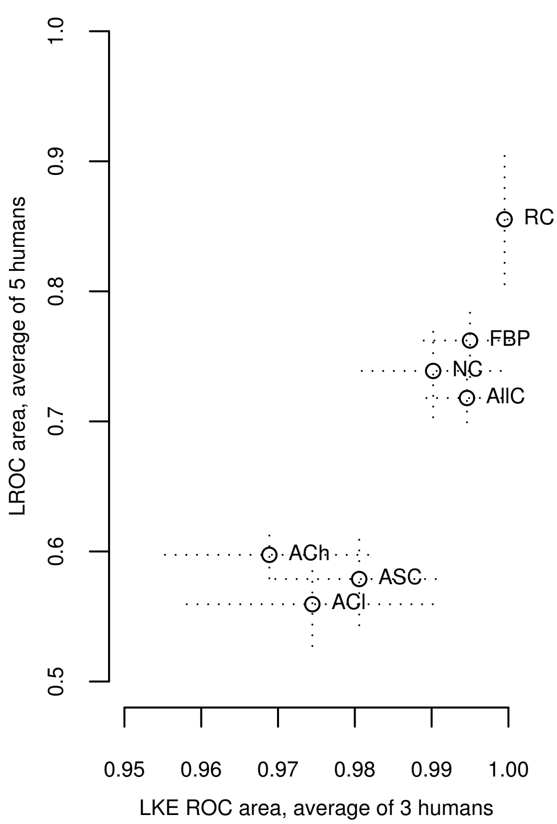

Fig. 4. Human observer area under the LROC curve vs. area under the LKE ROC curve. Note the axis have different scales. Dotted lines indicate error bars.

level.

Figure 4 compares human observers performing the LKE lesion detection task (ROC) with humans performing a lesion search task (LROC) on the same images. The attenuation-correction strategies are clustered together, showing inferior performance for both the LKE and LROC search tasks. Resolution correction (RC) was the best reconstruction algorithm for both the search and LKE lesion-detection tasks. The Spearman rank-correlation coefficient between the LROC area and the LKE ROC area is $r_s = 0.86$ ($p < 0.01$).

As expected, the area under the ROC curves is much higher than the area under the corresponding LROC curves. ROC gurus suggest that when comparing reconstruction algorithms, the average AUC should be in the ballpark of 0.87 for maximum power. We have found getting performance in this region on an LKE task requires lowering the lesion contrast to levels far below what would be seen in clinical practice. A search task is more difficult, so an average AUC near the sweet spot can be achieved with clinically realistic lesion contrasts.

Much of the measured decrease in observer performance due to attenuation correction may be due to not modeling lesion attenuation in our simulation, or to using the parametric bootstrap to add noise to the clinical background. For more details see our other paper in these proceedings [12].

IV. Conclusion

Although attenuation correction improves quantitative estimates of lesion uptake, for example the contrast-recovery ratio, attenuation correction does not necessarily improve observer performance on lesion search and detection tasks. In the case of SPN lung lesions, we have found that attenuation correction may reduce performance. We first saw decreased performance on lesion search tasks, and in this study showed a similar effect for LKE-detection tasks. This suggests that, for the hybrid data set studied here, attenuation correction hindered search tasks by making the lesion less visible, not by distracting the observer's attention to another part of the image.

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