The Effects of Compensation for Scatter, Lead X-Rays, and High-Energy Contamination on Tumor Detectability and Activity Estimation in Ga-67 Imaging

G. El Fakhri, M. F. Kijewski, P. Maksud, and S. C. Moore

***Abstract*—Compton scatter, lead X-rays, and high-energy contamination are major factors affecting image quality in Ga-67 imaging. Scattered photons detected in one photopeak window include photons exiting the patient at energies within the photopeak, as well as higher energy photons which have interacted in the collimator and crystal and lost energy. Furthermore, lead X-rays can be detected in the main energy photopeak (93 keV). We have previously developed two energy-based methods, based on artificial neural networks (ANN) and on a generalized spectral (GS) approach to compensate for scatter, high-energy contamination, and lead X-rays in Ga-67 imaging. For comparison, we considered also the projections that would be acquired in the clinic using the optimal energy windows (WIN) we have reported previously for tumor detection and estimation tasks for the 93, 185, and 300 keV photopeaks. The aim of the present study is to evaluate under realistic conditions the impact of these phenomena and their compensation on tumor detection and estimation tasks in Ga-67 imaging. ANN and GS were compared on the basis of performance of a three-channel Hotelling observer (CHO), in detecting the presence of a spherical tumor of unknown size embedded in an anatomic background as well as on the basis of estimation of tumor activity. Projection datasets of spherical tumors ranging from 2 to 6 cm in diameter, located at several sites in an anthropomorphic torso phantom, were simulated using a Monte Carlo program that modeled all photon interactions in the patient as well as in the collimator and the detector for all decays between 91 and 888 keV. One hundred realistic noise realizations were generated from each very-low-noise simulated projection dataset. The presence of scatter degraded both CHO signal-to-noise ratio (SNR) and estimation accuracy. On average, the presence of scatter led to a 12% reduction in CHO SNR. Correcting for scatter further diminished CHO SNR but to a lesser extent with ANN (5% reduction) than with GS (12%). Both scatter corrections improved performance in activity estimation. ANN yielded better precision (1.8% relative standard deviation) than did GS (4%) but greater average bias (5.1% with ANN, 3.6% with GS).**

***Index Terms*—Activity estimation, artificial neural networks, Compton scatter, cross talk, Ga-67 imaging, lead X-rays, lesion detection.**

Manuscript received December 6, 2002; revised March 14, 2003. This work was supported in part by the National Institutes of Health under Grants RO1-CA78936 and EB000802.

G. El Fakhri, M. F. Kijewski, and S. C. Moore are with the Department of Radiology, Harvard Medical School, Brigham and Women's Hospital, Boston, MA 02115 USA (email: elfakhri@bwh.harvard.edu).

P. Maksud is with the University of Paris XI, Paris, France, and also with the French Institute of Health (INSERM U494), Paris 75013, France.

Digital Object Identifier 10.1109/TNS.2003.812446

I. Introduction

GALLIUM SPECT imaging is used for detection and staging of non-Hodgkin's lymphoma, as well as of other cancers [1]. The energy decay scheme of Ga-67 is characterized by photon emissions principally at 91 and 93 keV (42% abundance), 185 keV (21%), 209 keV (2%), and 300 keV (17%). High-energy photons (e.g., 393, 494, 703, 794, and 888 keV) are of low abundance (5% at 393 keV, less than 1% for all others), yet these contaminant photons have an increased probability of penetrating through, or scattering in, the collimator and/or crystal and contributing to other photopeaks as downscatter. Furthermore, photons can contribute to lower energy windows either by scattering or by generating lead X-rays. Therefore, scatter, lead X-rays and high-energy contamination can have a major impact on image quality in Ga-67. The impact of these factors on tumor detectability in Ga-67 imaging has not been thoroughly investigated. Farncombe *et al.* [2] have reported a degradation of tumor detectability due to scatter in the patient, based on simulated data for the 93 and 185 keV photopeaks only, and assuming an idealized collimator (i.e., neglecting interactions in the collimator and the detector as well as high-energy contamination).

Despite the large number of scatter correction methods proposed in the literature, most approaches have been developed for low-energy radionuclides such as ^{99m}Tc or ^{201}Tl. Because there is a clear need for improved quantitative accuracy in SPECT imaging of higher energy radionuclides, we have recently developed two energy-based methods to correct for scatter, lead X-rays and high-energy contamination in ^{67}Ga imaging under realistic clinical conditions [3], [4]. Both approaches make use of projection images recorded in many energy windows to estimate the number of primary photons in each projection pixel that are attributable to the 93, 185, and 300 keV photons.

Finally, there has been to our knowledge no report on the the impact of corrections for scatter, lead X-rays, and high-energy contamination on tumor detectability under realistic clinical conditions and using a comprehensive physical model. The aim of the present work is to quantify the impact of these factors on tumor detectability and estimation of tumor activity concentration and to assess the effects of compensation for these factors on performance in these tasks.

Representative Results:

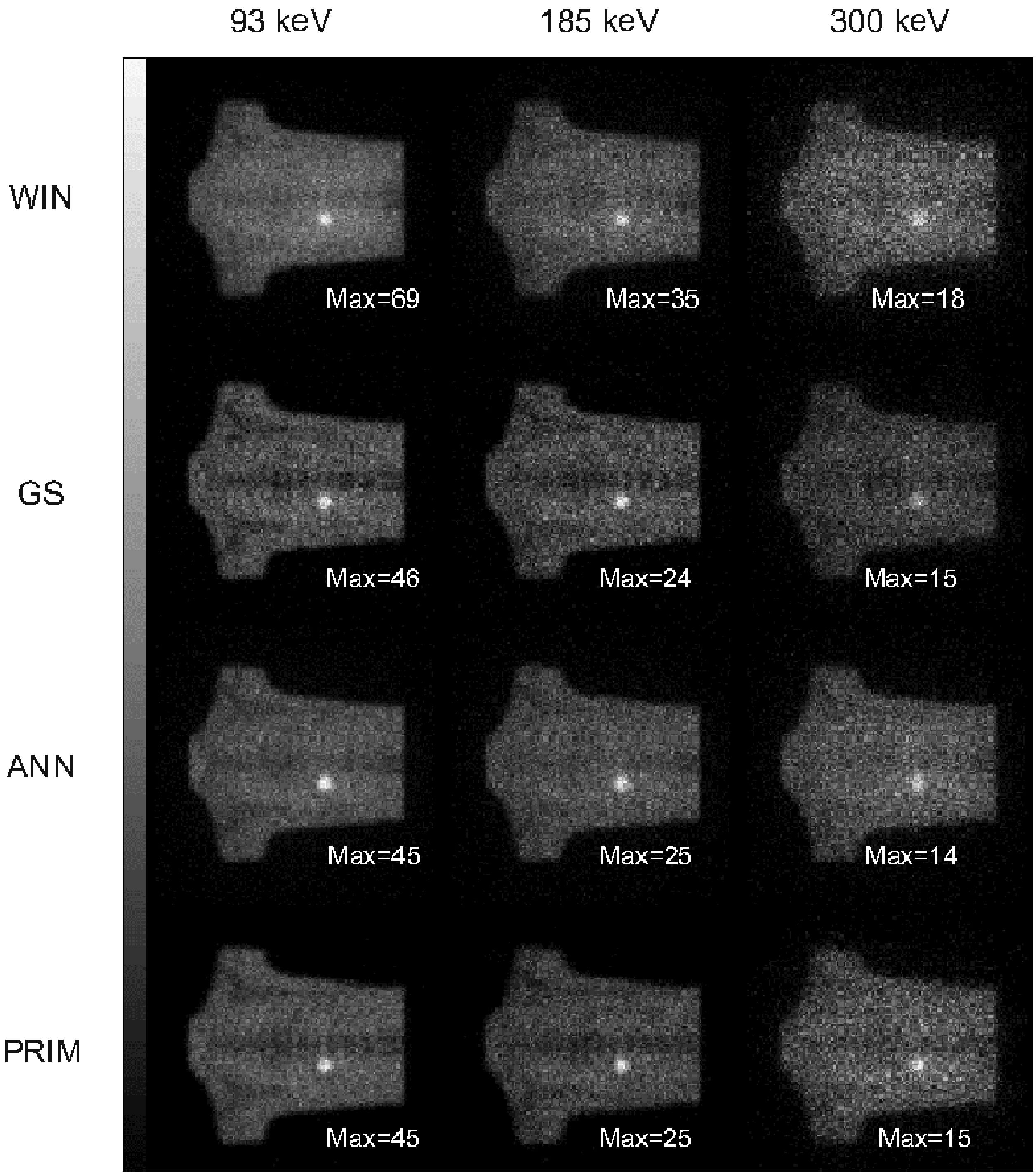

Fig. 4. Low noise Monte Carlo simulated posterior projections (showing one of the seven spherical lesions) corrected for scatter using WIN, GS, and ANN as well as the reference primary (scatter free) photons for the 93, 185, and 300 keV photopeaks. The gray scale is scaled separately for each image to its own maximum pixel value.