Improved activity estimation with MC-JOSEM versus TEW-JOSEM in ^{111}In SPECT

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We have previously developed a fast Monte Carlo (MC)-based joint ordered-subset expectation maximization (JOSEM) iterative reconstruction algorithm, MC-JOSEM. A phantom study was performed to compare quantitative imaging performance of MC-JOSEM with that of a triple-energy-window approach (TEW) in which estimated scatter was also included additively within JOSEM, TEW-JOSEM. We acquired high-count projections of a 5.5 cm^3 sphere of ^{111}In at different locations in the water-filled torso phantom; high-count projections were then obtained with ^{111}In only in the liver or only in the soft-tissue background compartment, so that we could generate synthetic projections for spheres surrounded by various activity distributions. MC scatter estimates used by MC-JOSEM were computed once after five iterations of TEW-JOSEM. Images of different combinations of liver/background and sphere/background activity concentration ratios were reconstructed by both TEW-JOSEM and MC-JOSEM for 40 iterations. For activity estimation in the sphere, MC-JOSEM always produced better relative bias and relative standard deviation than TEW-JOSEM for each sphere location, iteration number, and activity combination. The average relative bias of activity estimates in the sphere for MC-JOSEM after 40 iterations was −6.9%, versus −15.8% for TEW-JOSEM, while the average relative standard deviation of the sphere activity estimates was 16.1% for MC-JOSEM, versus 27.4% for TEW-JOSEM. Additionally, the average relative bias of activity concentration estimates in the liver and the background for MC-JOSEM after 40 iterations was −3.9%, versus −12.2% for TEW-JOSEM, while the average relative standard deviation of these estimates was 2.5% for MC-JOSEM, versus 3.4% for TEW-JOSEM. MC-JOSEM is a promising approach for quantitative activity estimation in ^{111}In SPECT. © *2008 American Association of Physicists in Medicine*. [DOI: 10.1118/1.2907561]

Key words: iterative reconstruction, Monte Carlo simulation, OSEM, ^{111}In SPECT, MC-JOSEM

I. INTRODUCTION

^{111}In-labeled radiopharmaceuticals have been increasingly used as surrogates for bio-distribution studies of the same compounds labeled with ^{90}Y for radionuclide therapy. Such studies often depend on obtaining quantitative estimates of the concentration of ^{111}In in tumor(s) and in various organs. Unfortunately, however, single photon emission computed tomography (SPECT) images are degraded by statistical noise, photon attenuation, and scatter in the patient, collimator, and detector, as well as by the finite spatial resolution of the collimator and detector, which leads to the so-called "partial volume effect." ^{111}In images are comprised of primary photons detected at nearly the same energy as they had when they were emitted, as well as scattered photons either detected within the same photopeak energy window or "down scattered" to the lower energy window, e.g., 245 keV photons which scatter such that they lose sufficient energy to be detected ultimately in the 171 keV energy window. These characteristics of ^{111}In imply that compensation for scatter and down scatter are likely to be particularly challenging for this radionuclide.

One energy-based approach that can be used to compensate for scatter and cross talk is the triple-energy window (TEW) method,[1] in which the number of scattered photons in a photopeak window is estimated using a linear interpolation of the counts within two adjacent narrow subwindows. The TEW method is not only straightforward to implement and efficient, but it can also account for scatter arising from outside the axial field of view. Ichihara *et al.*[2] showed that this method can be applied to several different radionuclides, and even used to correct for scatter and cross talk when imaging two simultaneously acquired radionuclides. Although the TEW approach can also compensate to some extent for scatter within the collimator, it cannot be used to correct for collimator penetration[3] or for coherent scatter within the collimator; this is because the energy of penetrating and coherently scattered photons is unchanged, so any method based solely on energy spectral analysis cannot accommodate these effects. Finally, as also pointed out by Zaidi and Koral,[3] the TEW method can lead to noisy estimates of scatter, since few counts are generally detected within narrow (usually 3–6 keV wide) scatter windows.

Published results on quantitative ^{111}In SPECT are fairly limited. A quantitative ^{111}In SPECT study using a simple physical phantom was described by Gilland *et al.*[4] Also, ^{111}In-labeled antibody activity in the livers of beagle dogs was quantified by Leichner *et al.*[5] However, both of these studies relied on analytic reconstruction algorithms which

Representative Results:

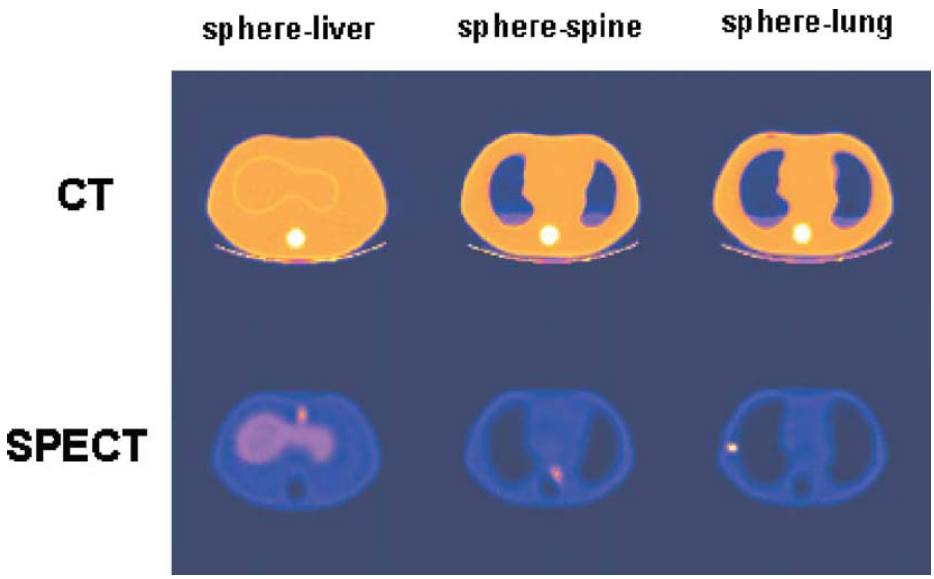

FIG. 3. Transverse registered CT and SPECT slices through the sphere at three different locations. From left to right, the sphere was attached to the liver, the spine, and the lung.

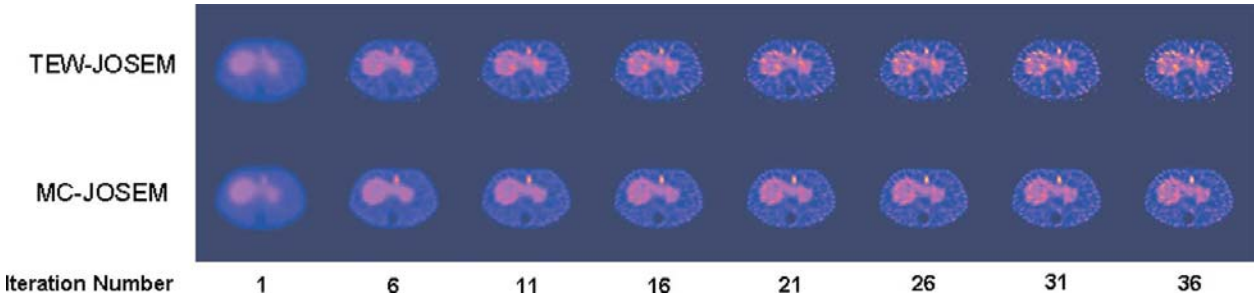

FIG. 4. A transverse slice through the sphere on the liver reconstructed by TEW-JOSEM and MC-JOSEM at different iteration numbers for one of the C1 noise realizations.

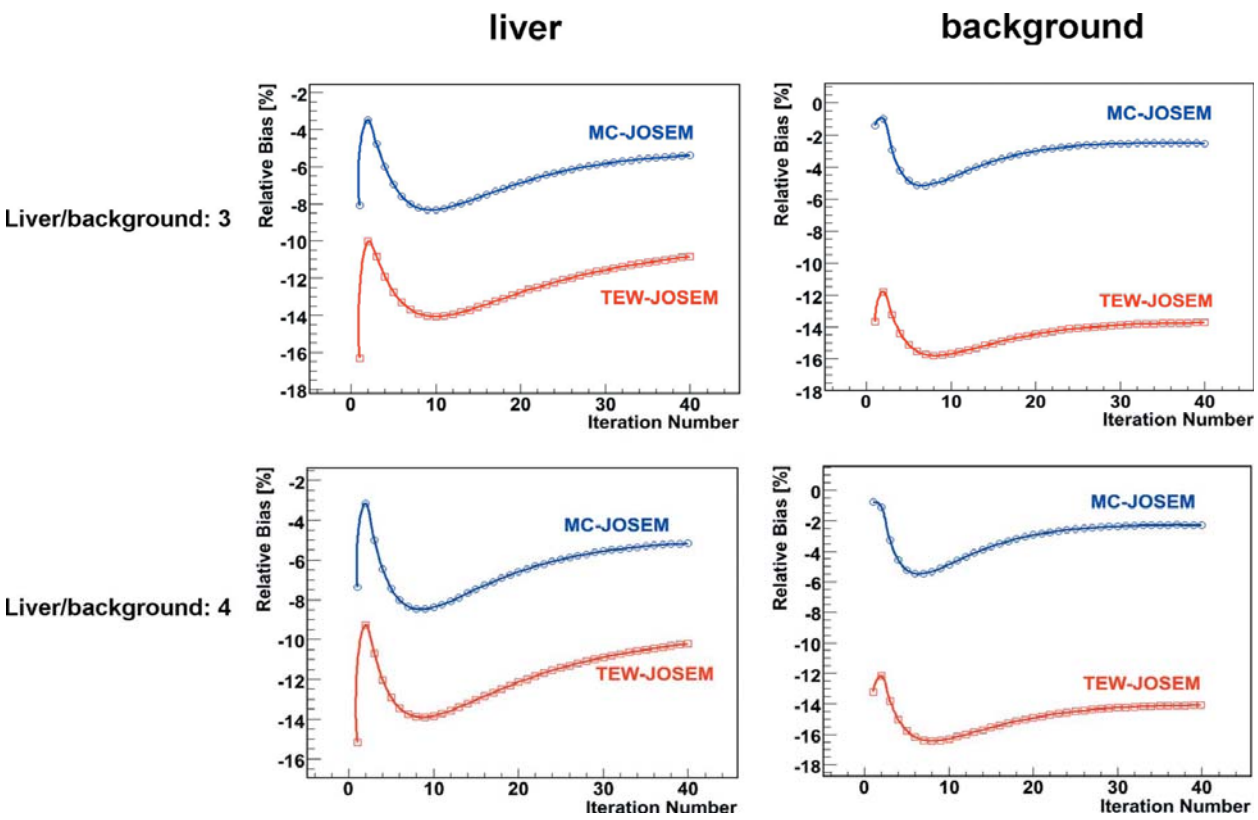

FIG. 6. Relative bias of ^{111}In activity concentration estimates in the liver and the background.

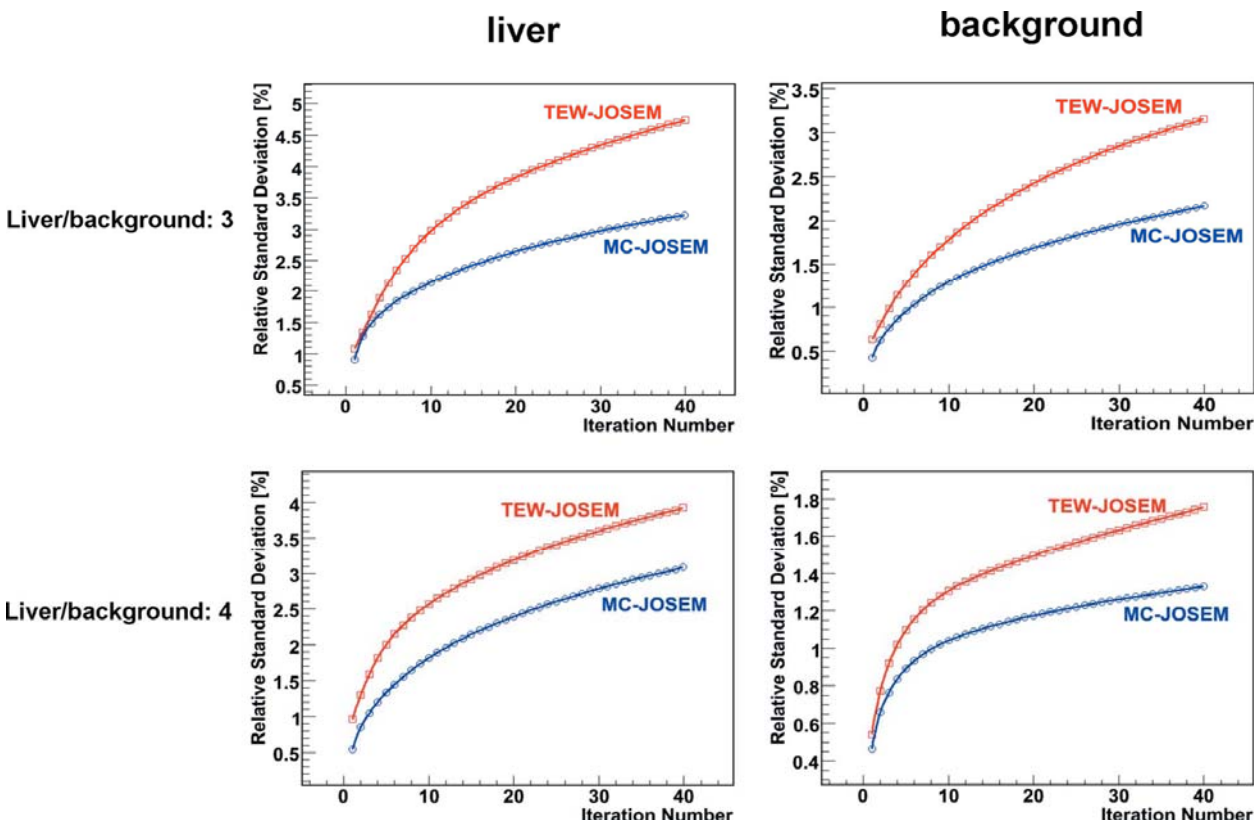

FIG. 9. Relative standard deviation of ^{111}In activity concentration estimates in the liver and the background.