Fast Monte Carlo based joint iterative reconstruction for simultaneous $^{99m}Tc/^{123}I$ SPECT imaging

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Simultaneous $^{99m}Tc/^{123}I$ SPECT allows the assessment of two physiological functions under identical conditions. The separation of these radionuclides is difficult, however, because their energies are close. Most energy-window-based scatter correction methods do not fully model either physical factors or patient-specific activity and attenuation distributions. We have developed a fast Monte Carlo (MC) simulation-based multiple-radionuclide and multiple-energy joint ordered-subset expectation-maximization (JOSEM) iterative reconstruction algorithm, MC-JOSEM. MC-JOSEM simultaneously corrects for scatter and cross talk as well as detector response within the reconstruction algorithm. We evaluated MC-JOSEM for simultaneous brain profusion (^{99m}Tc-HMPAO) and neurotransmission (^{123}I-altropane) SPECT. MC simulations of ^{99m}Tc and ^{123}I studies were generated separately and then combined to mimic simultaneous $^{99m}Tc/^{123}I$ SPECT. All the details of photon transport through the brain, the collimator, and detector, including Compton and coherent scatter, septal penetration, and backscatter from components behind the crystal, were modeled. We reconstructed images from simultaneous dual-radionuclide projections in three ways. First, we reconstructed the photopeak-energy-window projections (with an asymmetric energy window for ^{123}I) using the standard ordered-subsets expectation-maximization algorithm (NSC-OSEM). Second, we used standard OSEM to reconstruct ^{99m}Tc photopeak-energy-window projections, while including an estimate of scatter from a Compton-scatter energy window (SC-OSEM). Third, we jointly reconstructed both ^{99m}Tc and ^{123}I images using projection data associated with two photopeak energy windows and an intermediate-energy window using MC-JOSEM. For 15 iterations of reconstruction, the bias and standard deviation of ^{99m}Tc activity estimates in several brain structures were calculated for NSC-OSEM, SC-OSEM, and MC-JOSEM, using images reconstructed from primary (unscattered) photons as a reference. Similar calculations were performed for ^{123}I images for NSC-OSEM and MC-JOSEM. For ^{123}I images, dopamine binding potential (BP) at equilibrium and its signal-to-noise ratio (SNR) were also calculated. Our results demonstrate that MC-JOSEM performs better than NSC- and SC-OSEM for quantitation tasks. After 15 iterations of reconstruction, the relative bias of ^{99m}Tc activity estimates in the thalamus, striata, white matter, and gray matter volumes from MC-JOSEM ranged from −2.4% to 1.2%, while the same estimates for NSC-OSEM (SC-OSEM) ranged from 20.8% to 103.6% (7.2% to 41.9%). Similarly, the relative bias of ^{123}I activity estimates from 15 iterations of MC-JOSEM in the striata and background ranged from −1.4% to 2.9%, while the same estimates for NSC-OSEM ranged from 1.6% to 10.0%. The relative standard deviation of ^{99m}Tc activity estimates from MC-JOSEM ranged from 1.1% to 4.8% versus 1.2% to 6.7% (1.2% to 5.9%) for NSC-OSEM (SC-OSEM). The relative standard deviation of ^{123}I activity estimates using MC-JOSEM ranged from 1.1% to 1.9% versus 1.5% to 2.7% for NSC-OSEM. Using the ^{123}I dopamine BP obtained from the reconstruction produced by primary photons as a reference, the result for MC-JOSEM was 50.5% closer to the reference than that of NSC-OSEM after 15 iterations. The SNR for dopamine BP was 23.6 for MC-JOSEM as compared to 18.3 for NSC-OSEM.
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Key words: dual-radionuclide, brain SPECT, fast Monte Carlo, joint, OSEM, JOSEM, MC-JOSEM

I. INTRODUCTION

SPECT images are degraded by statistical noise, attenuation, scatter, detector response, and limited spatial resolution. Simultaneous $^{99m}Tc/^{123}I$ brain SPECT is particularly challenging because the emission energies of ^{99m}Tc (140 keV) and ^{123}I (159 keV) are very close; not only are down-scattered ^{123}I photons detected in the ^{99m}Tc window, but, equally importantly, primary photons of each radionuclide are detected in the wrong window (cross talk), making the discrimination between them on the basis of energy challenging. We and others have proposed several approaches to compensate for scatter, cross talk, and high-energy septal penetration in simultaneous $^{99m}Tc/^{123}I$ imaging,[1–3] and have recently tested them successfully in clinical brain studies.[4] The relative bias

Representative Results:

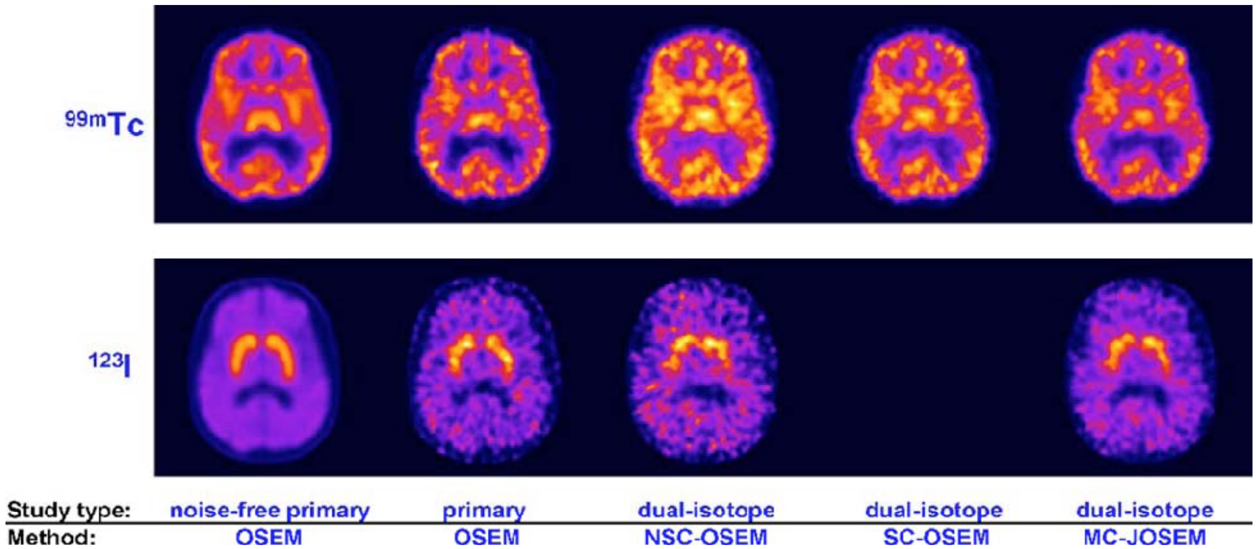

FIG. 3. Comparison of reconstructed images after five iterations. The images in the top and bottom rows are for 99mTc and 123I, respectively. The images in the first, second, third, fourth, and fifth columns were reconstructed using noise-free primary projections by OSEM, noisy primary projections by OSEM, noisy dual-radionuclide projections by NSC-OSEM, noisy dualradionuclide projections by SC-OSEM, and noisy dual-radionuclide projections by MC-JOSEM, respectively.

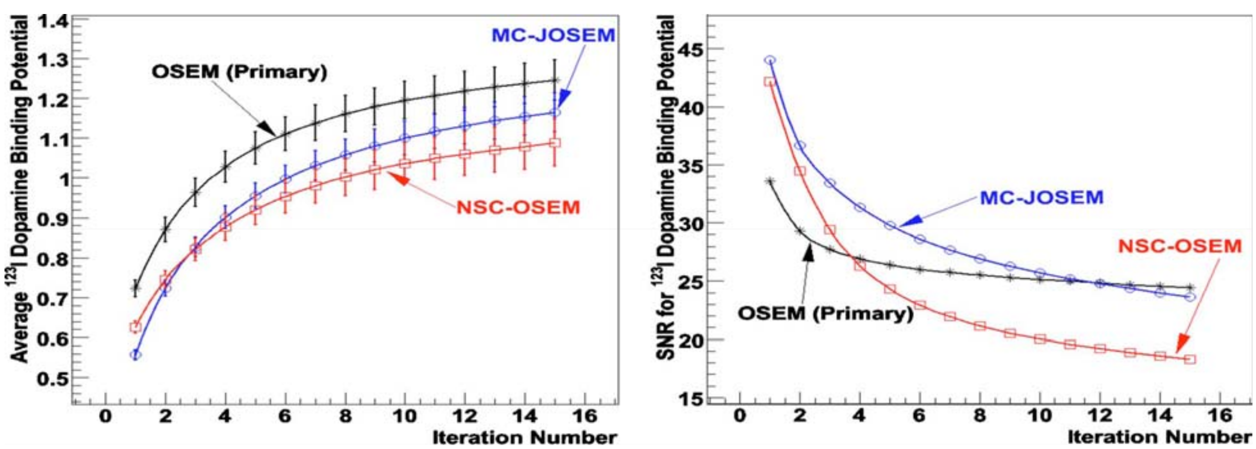

FIG. 8. ^{123}I dopamine BP and its signal-to-noise ratio. According to the original reference image used as the input for MC simulation, the ^{123}I dopamine BP has a value of 2.