Generalized five-dimensional dynamic and spectral factor analysis

Georges El Fakhri[a)]
*Department of Radiology, Harvard Medical School and Brigham and Women's Hospital, Boston,
Massachusetts 02115*

Arkadiusz Sitek
*Functional Imaging and Nuclear Medicine, Ernest Orlando Lawrence Berkeley National Laboratory,
Berkeley, California 94720*

Robert E. Zimmerman and Jinsong Ouyang
*Department of Radiology, Harvard Medical School and Brigham and Women's Hospital, Boston,
Massachusetts 02115*

We have generalized the spectral factor analysis and the factor analysis of dynamic sequences
(FADS) in SPECT imaging to a five-dimensional general factor analysis model (5D-GFA), where
the five dimensions are the three spatial dimensions, photon energy, and time. The generalized
model yields a significant advantage in terms of the ratio of the number of equations to that of
unknowns in the factor analysis problem in dynamic SPECT studies. We solved the 5D model using
a least-squares approach. In addition to the traditional non-negativity constraints, we constrained
the solution using *a priori* knowledge of both time and energy, assuming that primary factors
(spectra) are Gaussian-shaped with full-width at half-maximum equal to gamma camera energy
resolution. 5D-GFA was validated in a simultaneous pre-/post-synaptic dual isotope dynamic phantom study where ^{99m}Tc and ^{123}I activities were used to model early Parkinson disease studies.
5D-GFA was also applied to simultaneous perfusion/dopamine transporter (DAT) dynamic SPECT
in rhesus monkeys. In the striatal phantom, 5D-GFA yielded significantly more accurate and precise
estimates of both primary ^{99m}Tc (bias=6.4% ±4.3%) and ^{123}I (−1.7% ±6.9%) time activity curves
(TAC) compared to conventional FADS (biases=15.5% ±10.6% in ^{99m}Tc and 8.3% ±12.7% in ^{123}I,
$p < 0.05$). Our technique was also validated in two primate dynamic dual isotope perfusion/DAT
transporter studies. Biases of ^{99m}Tc-HMPAO and ^{123}I-DAT activity estimates with respect to estimates obtained in the presence of only one radionuclide (sequential imaging) were significantly
lower with 5D-GFA (9.4% ±4.3% for ^{99m}Tc-HMPAO and 8.7% ±4.1% for ^{123}I-DAT) compared to
biases greater than 15% for volumes of interest (VOI) over the reconstructed volumes ($p < 0.05$).
5D-GFA is a novel and promising approach in dynamic SPECT imaging that can also be used in
other modalities. It allows accurate and precise dynamic analysis while compensating for Compton
scatter and cross-talk. © *2006 American Association of Physicists in Medicine.*
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I. INTRODUCTION

Factor analysis is a powerful technique that allows the decomposition of a spectral or temporal image sequence into a small number of fundamental functions (factors) whose associated spatial distributions are called factor images. This, in turn, yields a synthetic representation of the contents of a relatively large dynamic or spectral image dataset. The major drawback of factor analysis, which precludes quantitation, is the nonuniqueness of the solution.[1] Several techniques have been developed that address this problem, in the time (dynamic studies) or energy (spectral studies) domains, in order to constrain the solution space and make the factor analysis approach more quantitative.[2–7] These techniques are based on the use of *a priori* physiological information and are, therefore, tailored for a particular type of clinical study. The separation between dynamic and spectral studies in single photon emission computed tomography (SPECT) is artificial since any dynamic study contains both energy and time dimensions. For example, when acquiring dynamic frames following injection of a radiotracer, every time frame can be acquired in multiple energy bins (where each energy bin represents the detected photons with energies in the corresponding range) or in list mode. Therefore, spectra can be plotted for each voxel of a given time frame. Traditionally, factor analysis of dynamic sequences (FADS) is applied in the time domain to projections or reconstructed frames, assuming scatter has been corrected for, and aims at extracting time varying factors that have physiological meaning (e.g., dynamic renal or cardiac studies). Likewise, spectral factor analysis is traditionally applied to projections at a given time frame and aims at compensating for Compton scatter by estimating the primary spectra and corresponding distributions.

The aim of the present work is to consider simultaneously energy and time domains using list-mode acquisitions and to
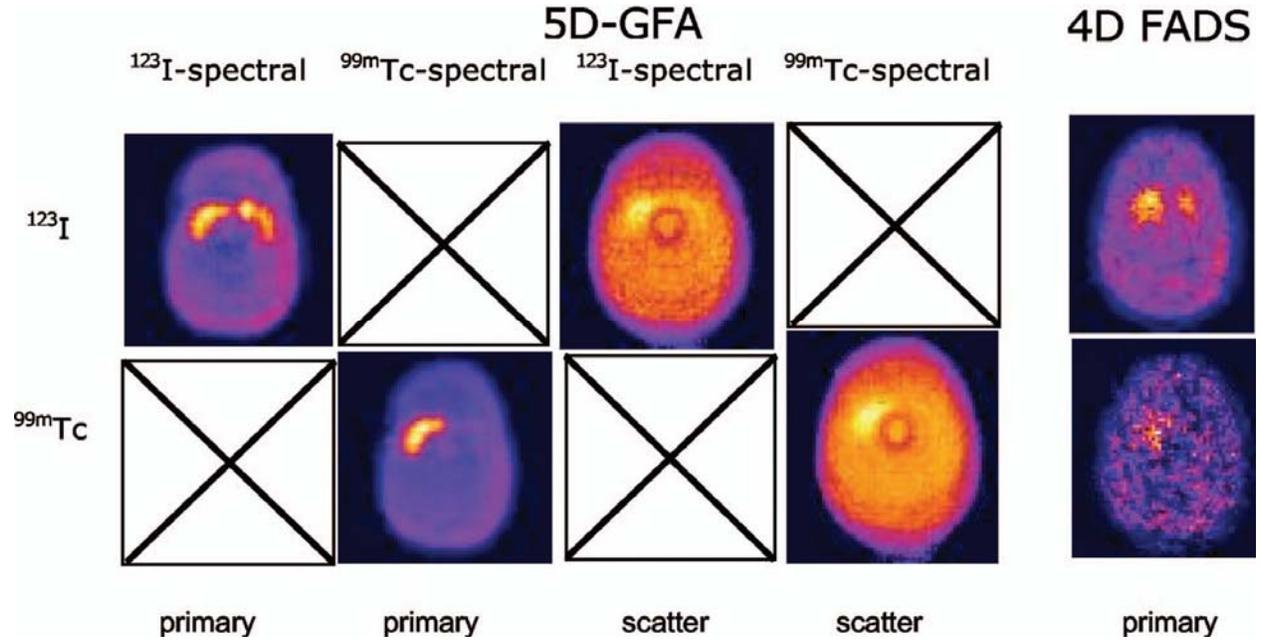
Representative Results:

FIG. 2. Estimated factor images for ^{123}I and ^{99m}Tc with 5D-GFA and 4D-FADS. 42=8 factor images are estimated with 5D-GFA. The crossed images indicate images of the factors that are *a priori* set to be zero. Primary factor images estimated with GFADS are shown in the first two columns and scatter factor images in the third and fourth columns.
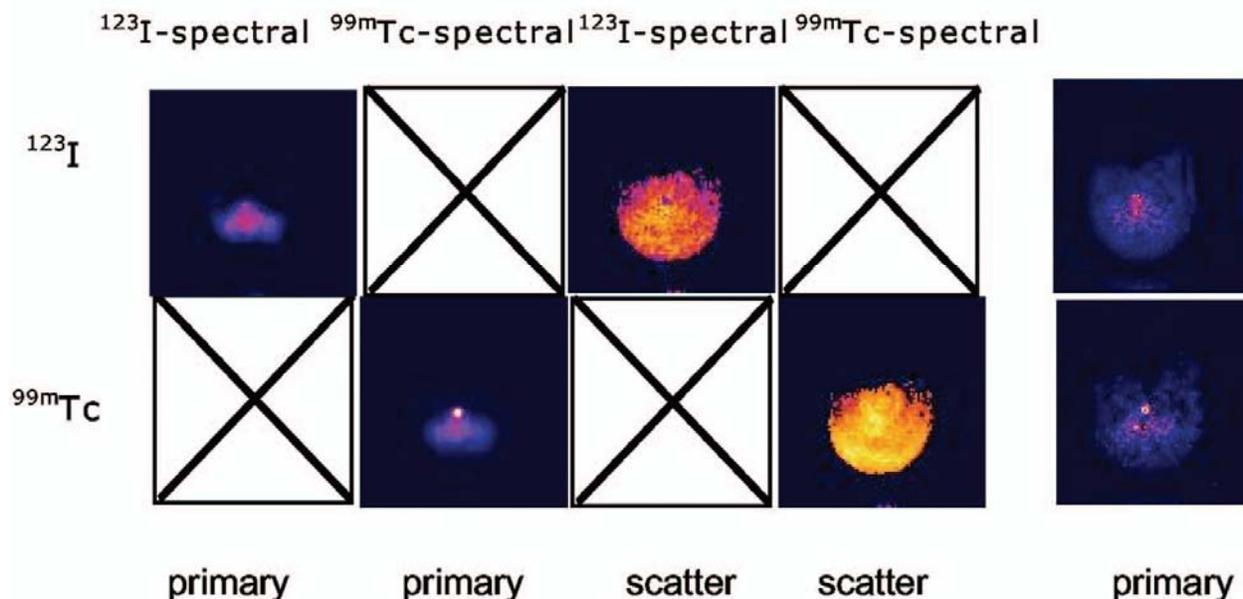
Point source 5D-GFA   4D FADS

^{123}I-spectral ^{99m}Tc-spectral ^{123}I-spectral ^{99m}Tc-spectral

primary   primary   scatter   scatter   primary

FIG. 5. 123I and 99mTc factor images estimated with 5D-GFA and FADS. The crossed images indicate images of the factors that are *a priori* set to zero. Primary factor images estimated with GFADS are shown in the first two columns and scatter factor images in the third and fourth columns.
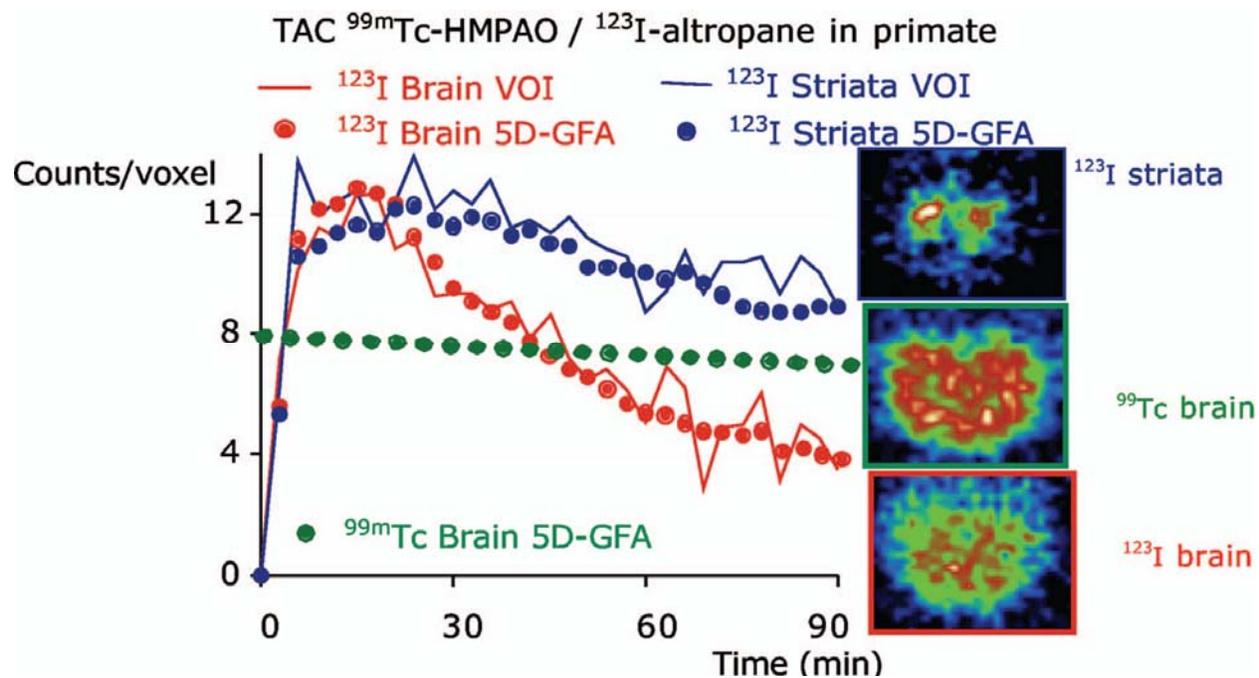

FIG. 6. ^{123}I-DAT and ^{99m}Tc-HMPAO factors and factor images estimated with 5D-GFA and time activity curves estimated with volumes of interest (VOI-TAC) for a rhesus monkey.