Instrumentation and Data Analysis: SPECT I: Reconstruction Algorithms

10:30–12:00 **Session 5** **Room 202**

No. 24

A FAST ITERATIVE RECONSTRUCTION METHOD BASED ON FUNCTIONAL REGIONS. Y. Zhang, N. H. Clinthorne, J. A. Fessler, W. L. Rogers. Division of Nuclear Medicine, University of Michigan, Ann Arbor, MI.

Iterative reconstruction methods offer the potential for improved quantitative accuracy over filtered backprojection because they accurately model the tomograph response and Poisson counting noise as well as allowing the use of spatially-varying side-information derived from MRI or CT images. However, because of their heavy computational burden and sometimes slow convergence rate, they are not yet practical in a clinical setting—especially in 3D where the number of voxels can easily exceed a quarter million.

To decrease the computational overhead we have developed a dual-grid iterative reconstruction method where the first pixel-grid is based on segmenting the reconstruction volume into regions over which the activity is potentially smoothly varying. These "functional-pixels" can be determined by mapping organ and region boundary data obtained from MRI or CT data into the ECT data. Reconstruction is performed first using an un-regularized solution objective on the coarse grid. When coarse-grid convergence is attained the reconstruction is mapped, *without smoothing*, onto a conventional fine grid of square pixels and further reconstruction is performed using a regularized solution criterion. If the boundaries of the functional regions have been determined accurately, the convergence rate will be greatly enhanced. Inaccuracies in region boundaries can be accounted for with some loss in convergence rate.

Evaluations of the method in 1D and 2D simulations with noiseless data have demonstrated that for approximately the same amount of computation, residuals from the dual-grid method are up to a factor of eight lower than those using the conventional, fine-grid-only method at 50 iterations. These performance advantages are likely to further increase in 3D because the functional-pixel to fine-grid-pixel ratio will generally be much smaller than in 1D or 2D.

The dual-grid method has the potential for greatly reducing the amount of computation in 3D iterative reconstruction, is easy to implement, and can be applied to both least-squares and maximum-likelihood solution objectives.

No. 25

A RECONSTRUCTION ALGORITHM USING SINGULAR VALUE DECOMPOSITION TO COMPENSATE FOR CONSTANT ATTENUATION IN SINGLE PHOTON EMISSION COMPUTED TOMOGRAPHY. G.T. Gullberg and G.L. Zeng. The University of Utah, Salt Lake City, UT.

The development of reconstruction algorithms to correct for constant attenuation has important application in SPECT imaging of the brain. Previously, a convolution reconstruction algorithm was developed which mathematically can be shown to be an accurate reconstruction of projections of emission sources within a constant attenuating media. The major problem with the algorithm is the severe noise amplification. The algorithm was derived based upon being able to represent the projection data as projections of the exponential Radon transform and uses an exponential backprojector after applying a reconstruction filter to the modified projection data. Due to the exponential backprojector, the point spread function of the backprojection has a hyperbolic cosine factor, which makes the point spread function non local and noise amplifying. Even if window functions are applied to the filters to try to remedy the noise amplification, the window functions do not help very much to improve the image quality in a noisy reconstruction. The new algorithm is derived from the singular value decomposition (SVD) of the exponential Radon transform. Using SVD to reconstruct an image, the projection data is first backprojected using the standard tomographic backprojection without the exponential term. The point spread function of the backprojection is local and easy to regularize. Using the SVD approach, regularization is accomplished by truncating the terms with small singular values. Computer simulations show an improvement in the SVD method over the convolution backprojection method when the projection data is corrupted with noise.

No. 26

LEAST SQUARES ALGORITHM FOR REGION-OF-INTEREST EVALUATION IN EMISSION TOMOGRAPHY. A.R. Formiconi, A. Passeri. University of Florence, Italy.

The performances of the least squares (LS) algorithm applied to region-of-interest (ROI) evaluation were studied by means of simulations and phantom studies. The LS algorithm is a direct algorithm which does not require any iterative computation scheme and also provides estimates of statistical uncertainties of the ROI values (covariance matrix). A model of physical factors, such as system resolution, attenuation and scatter, can be specified in the algorithm. In this paper an accurate model of the nonstationary geometrical response of a camera-collimator system was considered. The algorithm was compared with three others which are specialized for ROI evaluation, as well as with the conventional method of summing the reconstructed quantity over the ROI. For the latter method, two algorithms were used for image reconstruction: filtered backprojection and conjugate gradients with the model of nonstationary geometrical response. For noise-free data and for ROI of accurate shape LS estimates were unbiased within roundoff errors. For noisy data, estimates were still unbiased and the precision worsened slightly for ROI smaller than resolution: with a typical statistics of brain perfusion studies performed with a collimated camera, the estimated standard deviation for a 1 cm square ROI was 10% with an ultra high resolution collimator and 7 % with a low energy all purpose collimator. Using conventional ROI estimates with the conjugate gradient iterative algorithm and the model of nonstationary geometrical response, bias of estimates decreased on increasing the number of iterations, but precision worsened heavily thus achieving an estimated standard deviation of more than 25 % for the same 1 cm ROI. These results show that the LS algorithm with accurate modelling of physical factors applied to ROI evaluation allows to recover resolution effects with limited amplification of statistical fluctuations in comparison with techniques where image reconstruction is involved.

No. 27

CARDIAC SPECT RECONSTRUCTIONS WITH TRUNCATED PROJECTIONS IN DIFFERENT SPECT SYSTEM DESIGNS. B.M.W. Tsui, X.D. Zhao, P. Vernon*, D. Nowak*, J.R. Perry and W.H. McCartney. University of North Carolina at Chapel Hill, Chapel Hill, NC and *General Electric Medical Systems, Milwaukee, WI.

Truncated projections are found in cardiac SPECT acquisitions when imaging large patients and when using SPECT systems with the smaller detector sizes now commercially available. We studied the effects of truncated projections on cardiac SPECT images obtained from three rotating camera SPECT system designs. The first and second system designs had the camera(s) positioned centered and off-centered with respect to the axis-of-rotation, respectively. The third design consisted of two camera heads connected at a right angle and rotating around the patient as a single unit. Three camera sizes of 30, 35 and 40 cm were used in the study. Reconstruction methods included the conventional filtered backprojection (FBP) algorithm and iterative methods which provided improved image quality and quantitative accuracy. A simulation study was conducted using the three system designs and a realistic cardiac-chest phantom derived from CT scan of a normal size patient. The effects of the non-uniform attenuation in the chest region was included in the simulation. Transmission and emission projections from 180° and 360° acquisitions using the three system designs were first reconstructed using the FBP algorithm. In general, image artifacts and distortions were found in regions with missing projection data due to truncated projections and these were increased in 180° when compared with 360° reconstructions. The affected region was near the edge of the reconstructed image and away from the heart even for the smallest size camera. The artifacts and distortions could be reduced by extrapolating the projection data. Iterative reconstruction methods such as those using the maximum likelihood-expectation maximization (ML-EM) algorithm with attenuation compensation were found to provide the best image quality in terms of reduced image artifacts and distortions, and improved quantitative accuracy. We conclude that truncated projections can be effectively used in cardiac SPECT imaging as long as the heart stayed within the region with non-truncated projections and corrective reconstruction methods are used.

No. 28

MULTI-ENERGY MAXIMUM-LIKELIHOOD RECONSTRUCTION ALGORITHMS FOR SPECT AND PET. N.H. Clinthorne, X. Wang, J.A. Fessler, Division of Nuclear Medicine, The University of Michigan, Ann Arbor, MI.

Projection data acquired in multiple energy-windows can potentially be used to correct for Compton-scattering thereby improving quantita-

tive accuracy in SPECT and PET. The optimum reconstruction method would use the information in both the scattered and direct photons to estimate the object; however, this requires that the photon-transport matrix (relating the object to the projection data) be accurately known as a function of 3D spatial coordinate and energy. Moreover, this matrix is generally not sparse and will only be approximately known due to the unknown scattering properties of the object. We propose an alternative "maximum-likelihood" method that eliminates the need for a matrix accurately modeling both direct and scattered photon transport characteristics.

The method is based on augmenting the underlying complete-data marked point-process with an additional mark indicating whether a detected γ-ray is direct or scattered. The object intensity is then estimated solely from the direct emissions while the scattered photons are treated as an additive, projection-space interference process whose intensity is constrained to be smooth in both space and energy. This allows the transport matrix to be represented as two components: a spatial term, relating only the direct γ-rays to the object; and an energy term, describing the smearing of observed γ-ray energies by the tomograph. The EM algorithm is used for the reconstruction and constrains both the object and scattered photon intensities to be positive. To control noise, separate smoothness constraints are applied to the object and the scattered photon intensities.

While this technique ignores any object information in the scattered photons, this presents little real disadvantage because: (1) the amount of additional object information in the scatter is likely to be small, and (2) the use of this information requires perhaps unreasonably precise knowledge of the scattering properties of the object in order to determine the transport matrix.

The technique can be applied to PET and SPECT emission and transmission imaging as well as to situations where it is desirable to separate data resulting from simultaneous, multiple-isotope imaging.

No. 29

A GENERALIZED GIBBS PRIOR FOR MAXIMUM *A POSTERIORI*-EM SPECT RECONSTRUCTION WITH FAST AND STABLE CONVERGENCE PROPERTIES. D.S. Lalush and B.M.W. Tsui. The University of North Carolina at Chapel Hill, Chapel Hill, NC.

We introduce modifications to a previously-reported generalized Gibbs prior which improve the convergence properties of the Maximum *A Posteriori*, Expectation Maximization One-Step-Late (MAP-EM OSL) algorithm. The previously-introduced prior (*J Nucl Med* 32(5): 916, 1991) was designed to allow flexibility for the user to choose the relative amounts of smoothing of noise and edges in the iterated image estimates. It offered an improvement over Maximum Likelihood (ML) EM reconstructions in that there was considerably less of an increase in image noise at higher iterations. However, because the iterated image estimates did not converge to an image which was a maximum of the posterior probability function in a reasonable number of iterations, there was still a need to stop the iterative process of the MAP-EM OSL algorithm. The need for stopping rules for ML-EM is well known and has been an important hindrance to the clinical application of iterative reconstruction techniques. We added a component to the derivative of the Gibbs potential function which smooths all neighboring pixel differences above a certain level equally, thus combatting the tendency of individual noisy pixels to diverge at higher iterations. The modifications have improved the convergence of the algorithm to the point that it does reach a maximum of the posterior probability, i. e. the image estimates change very little thereafter, in a reasonable number of iterations (approximately 200). We demonstrate this on data simulated from a realistic cardiac phantom, derived from an X-ray CT study and average Tl-201 uptake distributions in patients, and SPECT data acquired from a 3D Hoffman brain phantom. Furthermore, we show that the final solution is independent of the initial image estimate, indicating that the algorithm does not fall into local maxima in the posterior probability function. We contrast this with the ML-EM case, in which the effects of initial estimates linger in the iterated image estimates. Finally, we show that the improved convergence comes at no cost to edge sharpness in the final image estimate. We conclude that the MAP-EM OSL algorithm with the modified prior offers important advantages over ML-EM, such as reduced image noise with sharp edges and a stable solution without a need for arbitrary stopping rules, and that these advantages are important in making iterative MAP solutions practical for clinical use.

Gastroenterology I: Transit and Motility

10:30–12:00 **Session 6** **Room 503**

No. 30

ROC-ANALYSIS FOR OPTIMIZING QUANTITATIVE RESULTS OF ESOPHAGEAL SCINTIGRAPHY. K. Tatsch, W. Voderholzer, S.A. Mueller-Lissner, and C.-M. Kirsch. Departments of Radiology and Internal Medicine, University of Munich, Munich, FRG

This study employs ROC (receiver operator characteristic) methodology to evaluate the diagnostic performance of a multiple swallow test for scintigraphic assessment of esophageal motility disorders.

47 pts were studied by esophageal scintigraphy (ES) and manometry. In ES the passage of liquid (l) and solid (s) test boluses was investigated with 6 swallows each. Quant. data (esophageal emptying (%)) were derived from a particularly created sum swallow. Processing was repeated by the same and a different observer to study intra- and inter-observer variability of ES-results. Manometric findings were used to define normal (n=26) vs. path. (n=21) function. Referring to this classification ES-results were categorized for various confidence thresholds.

Results of ROC-analyses:

esophageal emptying (%)		*70*	*75*	*80*	*85*	*90*	*95*	*100*
s-bolus:	sensitivity (%)	71	86	91	**95**	95	95	100
	specificity (%)	100	100	100	**96**	85	62	19
l-bolus:	sensitivity (%)	65	70	80	**80**	85	90	100
	specificity (%)	100	100	100	**96**	92	58	23

Optimal discrimination of normal vs. path. findings was obtained with the threshold set at 85%. At this level specif. was similar for l- and s-bolus studies but the latter provided higher sensitivity. Intra- and inter-observer variation of ES-data was neglectable not altering ROC results.

ROC-analysis applied to quantitative data of a multiple swallow test has shown to optimal discriminate normal from pathologic results (sensitivity 95%, specificity 96%) with the threshold of esophageal emptying set at 85%. Increase in sensitivity by comparable specificity suggest the use of s- rather than l-boluses for evaluating esophageal dysfunction. ROC-analysis may be employed to optimize thresholds for decision making in other quantitative parameters (e.g. transit time) as well.

No. 31

EFFECT OF ACUTE AND CHRONIC ALCOHOL ON ANTRAL PROCESSING OF A SOLID MEAL. LC Knight, AH Maurer, R Wikander, S Buczala, M Kollmann, V Abraham, J Romano, B Krevsky and R Fisher. Temple University School of Medicine, Philadelphia, PA.

The purpose of this study was to determine the effect of alcohol ingestion on the ability of the stomach to process and empty a solid meal. Seven dogs were studied as controls (no alcohol), restudied following acute alcohol ingestion, and studied again after conditioning for 4 months as "chronic alcoholics". For each study, the dog voluntarily ingested 6% ethanol solution to simulate beer (controls ingested water). Thirty min later, the dog was fed a meal of eggs labeled with 5 mCi Tc-99m sulfur colloid and mixed with 50g canned dog food. At 10-min intervals a dynamic series of 64 x 1-sec LAO images of the stomach was acquired to image antral contractions. For analysis, a narrow region was drawn across the antrum, perpendicular to the long axis of the stomach. Time-activity curves for this region were analyzed to determine frequencies and amplitude. The dominant frequency of contractions (5.9 per min) was not significantly altered by alcohol in any group. In both acute and chronic dogs, however, alcohol produced a dose-dependent reduction in the amplitude of antral contractions (mean ± SEM):

BLOOD ALCOHOL LEVEL	CONTROL	ACUTE	CHRONIC
no alcohol	56 ± 3	56 ± 3	46 ± 3
40 - 80 mg/DL		43 ± 4	37 ± 4
80 - 120 mg/DL		45 ± 5	35 ± 7
>120 mg/DL		36 ± 7	32 ± 2

Chronic alcoholic dogs studied in a state of sobriety showed impaired antral amplitudes compared to controls ($p<0.05$). At highest doses, peristaltic contractions were often completely abolished. The dose-dependent impairment of antral contractions correlated with delayed gastric emptying in the same dogs. Lag phase was prolonged while the terminal slope of emptying was unaffected. These data suggest that acute alcohol ingestion impairs gastric emptying of solid food in part by inhibiting antral contractions and that chronic alcohol ingestion may result in a persistent gastric motor disorder.

No. 32

CHARACTERIZATION OF GASTRIC MOTILITY DISTURBANCES IN DIABETES USING SCINTIGRAPHY. M.C Vekemans, J.L Urbain, R. Bouillon, M. Bex, J. Van Cauteren, S. Mayeur, V.V.d. Maegdenberg, G. Bataille, M. De Roo. K.U. Leuven and CHG Hornu.Belg.

Using the standard isotopic gastric emptying test combined with a new data acquisition and processing method, the contractions' characteristics of the stomach were analyzed and correlated to gastric retention in 10 diabetic patients with delayed gastric emptying (DD), 10 age and sex matched healthy controls (C) and in 10 diabetics with a normal gastric evacuation (DN). After ingestion of an egg sandwich test meal labeled with 2 mCi of Tc-99m-Sc, static and dynamic images of the stomach were acquired sequentially for 2 hours using a computerized dual-headed gamma camera. After decay correction, percentages of activity remaining in the total (TS), proximal (PS), distal and antral portions of the stomach were determined on static images at each time