INVESTIGATION OF MULTIPLE ENERGY RECONSTRUCTIONS IN SPECT USING MLEM. H.M. Hudson [1], B.F. Hutton [2], R. Larkin [1], and C. Walsh [1], 1) Dept. Statistics, Macquarie University and 2) Dept. Medical Physics, Westmead Hospital, Sydney, Australia.

Some radionuclides used in SPECT have dual or multiple energy characteristics (e.g. Tl-201, Ga-67) with corresponding differences in attenuation at different energies. We have investigated the application of maximum likelihood (MLEM) of multiple energy projection data incorporating correction for heterogeneous attenuation.

Simulated projections of a thorax phantom were based on Tl-201 emission at two energies. Results compared were 1) for the lower energy counts only, 2) for projection data pooled without regard to energy, reconstructed under attenuation assumptions valid for low energy photons, and 3) for simultaneous reconstruction using an ordered subsets (OSEM) approach. Two subsets were used corresponding to counts of either energy. MLEM provided iterative improvements to the reconstruction with each subset used in alternation. Consistent results were obtained for both 360° and 180° projection data. MSE comparisons were:

Reconstruction	360° (iteration)	180°
Low energy counts alone	114 (20)	108 (18)
pooled counts	96 (21)	95 (18)
simultaneous OSEM	94 (10)	89 (9)

Simultaneous reconstruction improved on single energy reconstructions, both in MSE and fit to observed projection data. However, the simple pooling of counts of all energies was equally effective except with extreme non-uniformity of attenuation. The visual appearance of the reconstruction and fit to observed projections was very similar for these methods. The computational effort is similar for all methods, as each OSEM iteration requires two EM iterations (one for each data subset). It appears that pooling is robust to the differences in attenuation at the two energies (here 0.14 vs 0.20 cm^{-1}) which - in principle, and as we observed with extremely non-uniform attenuation - produce bias. However, since OSEM exhibits no overheads and copes better with the non-uniform attenuation typical of clinical studies, we recommend simultaneous reconstruction.

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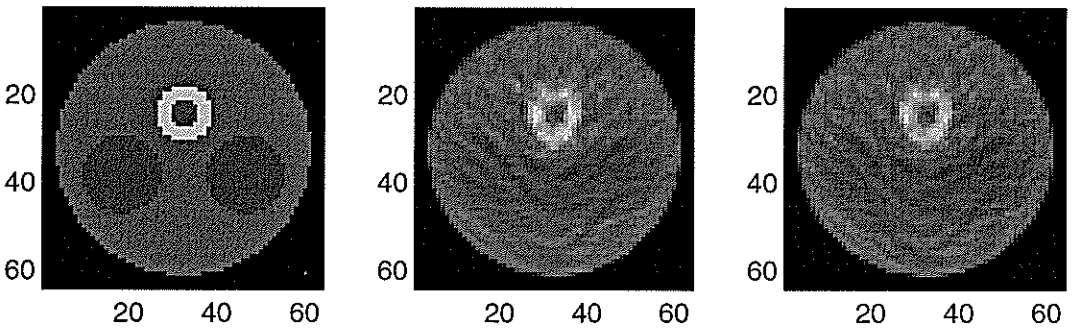


Figure 1: Thorax phantom, reconstructions using pooled projection data and simultaneous reconstruction using two subsets. MLEM iterations were conducted with projection counts as specified. In the case of pooled projections, the algorithm adjusted for attenuation under the assumptions valid for lower energy photons. Reconstructions are based on 180° projections with relative emission rate of lower to higher energy photons of 5:1.

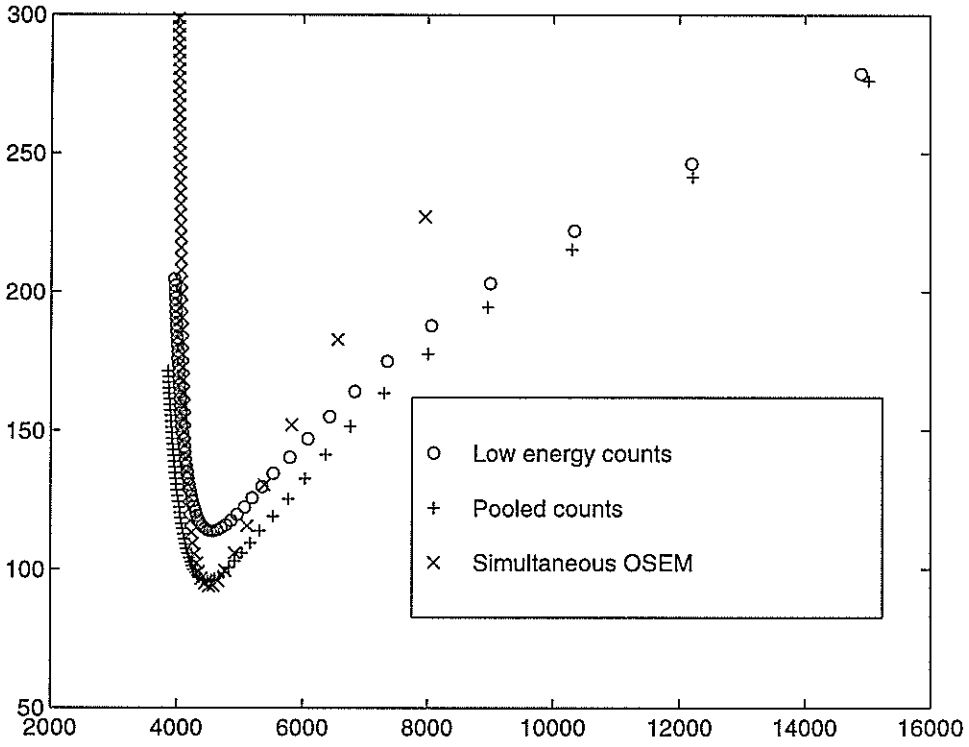
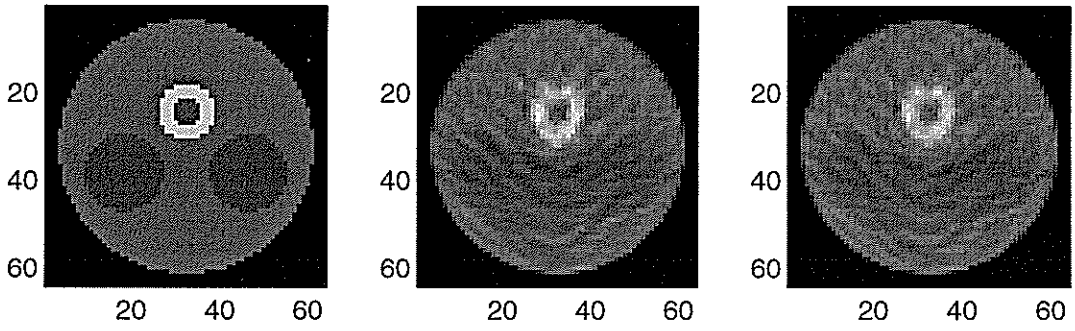


Figure 2: MSE versus measured fit to observed projections, 360° study. A chi-square statistic, CSQ, measures discrepancy between observed and expected projection counts. CSQ generally decreased in successive iterations, while MSE first decreased, then increased after an optimal number of iterations. Expected projections were obtained for both energies, based on corresponding attenuation assumptions. All reconstructions were scaled to the same total count as the phantom so that mean square error (MSE) could provide a meaningful estimate of accuracy.



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Dual Energy: MCAT

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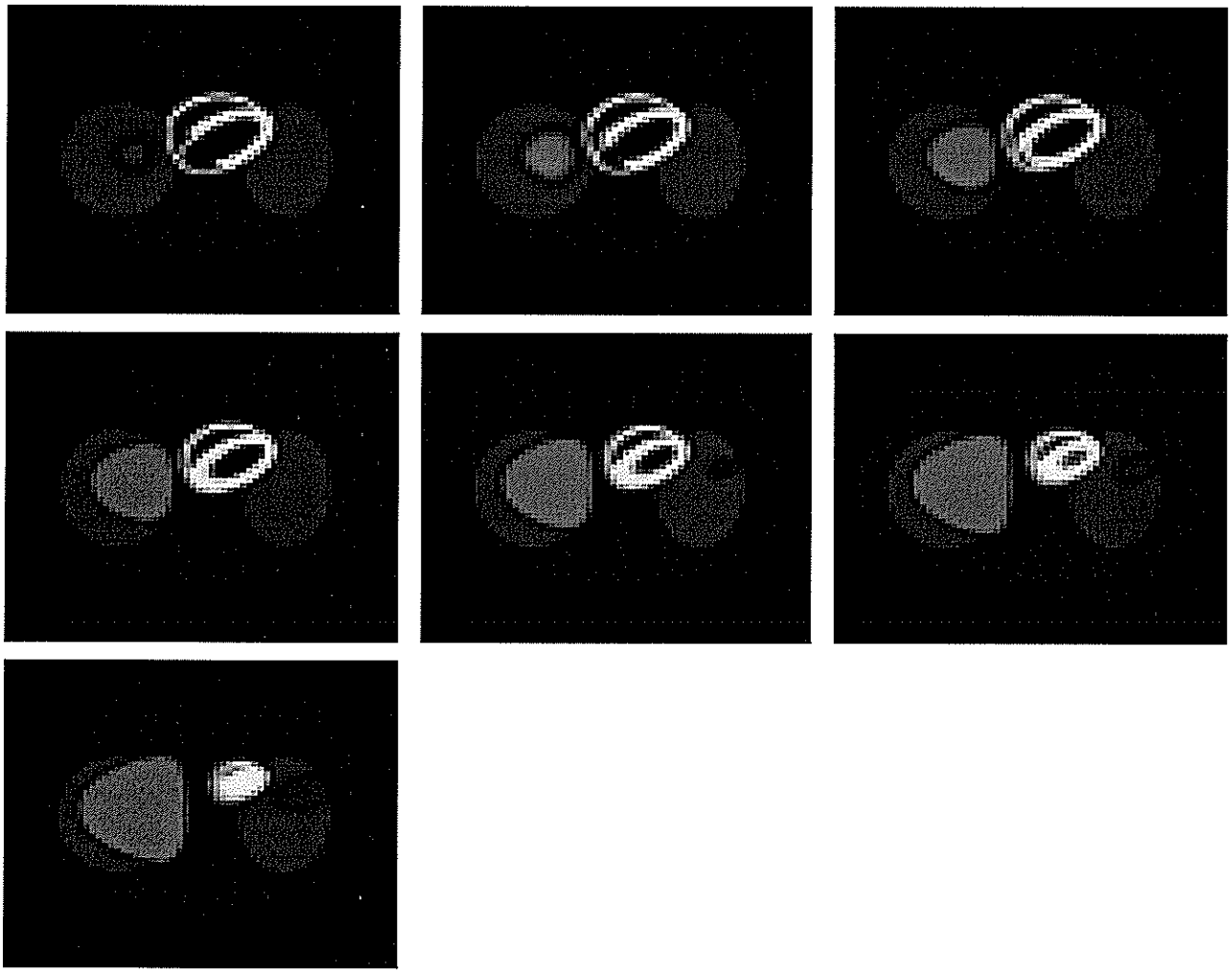
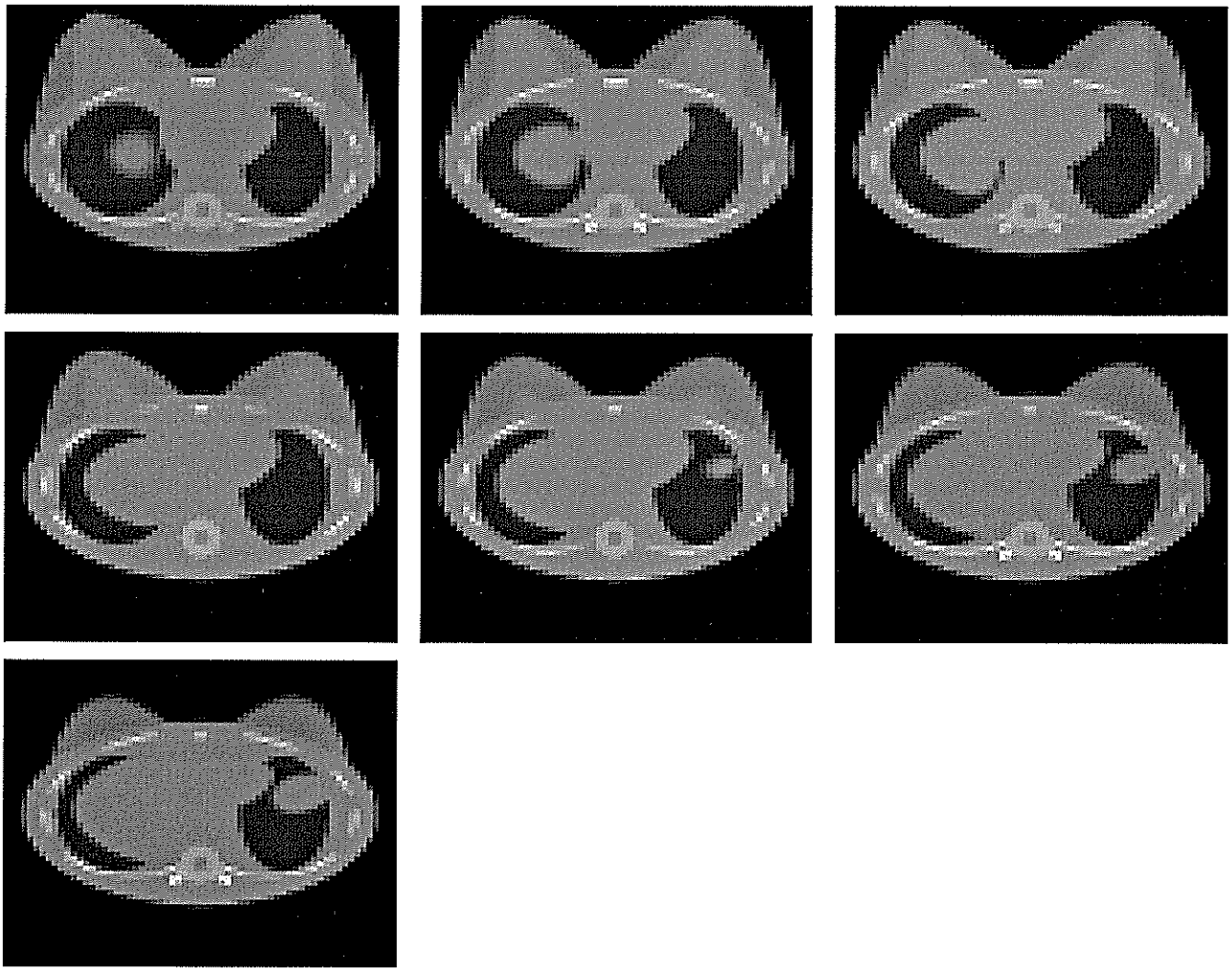
Objectives

- dual energy reconstruction
- realistic phantom (MCAT)
- non-uniform attenuation (chest, lungs)

MCAT phantom

- 7 slices provided in chest region
- [2 images: dualEnergy/MCATphn.eps, MCATattn]
- slice 4 reported (MCAT4)





Dual energy characteristics

- emitted counts
  - average per pixel set to 125 (64x64 grid)
  - total count 512 thousand
- [table]
- attenuation
  - base values from MCAT attenuation file (MCAT4a)
  - scaled by Aratio parameter for high energy
  - base values 0.000-0.292 /cm (bone)

Parameter settings

ENERGY	PROPN	ATTEN (tissue)
Low (72 keV)	78.5%	.196/cm
High (167 keV)	21.5%	.146/cm
EnergyAratio		0.70
EnergySratio	0.28	

Reconstruction methods

- Model:
  - mu_1 = A_1 x;
  - mu_2 = A_2 x (same x)
- Low energy alone
- Summed: sum of low and high
- simultaneous ML-EM (no ordered subsets here)

Previous results (RD1 phantom)

- Corrected chi-square results:
  - summed, ML very similar performance
  - summed requires more iterations to reduce deviance
- MSE significantly reduced: Summed and ML

  Lo 179 (5.5) S 113 (3.5) ML 101 (2.4)
- Similar result when restricted to HROI
- 360 degree > 180 deg
- Total count was 2 million?, 16 replications of noise

Comparison: Total counts: acquired/ reconstructed

Acquired	('000)
Low	59
High	28

[Table: reconstructed]

[Table: Mean reconstructed in HROI , 20x20 pixels]

*represents 78%

Reconstructed: total counts ‘000

ITN	L	H	ML
8	369	176	492
16	402	191	513
32	411	194	516
64	412	195	516

Mean counts: HROI

ITN	L	Summed	ML
16	388*	578	496
32	397*	589	500
64	398*	591	501
Correct	*388**	*494*	*494*

Errors in 64x64 pixels

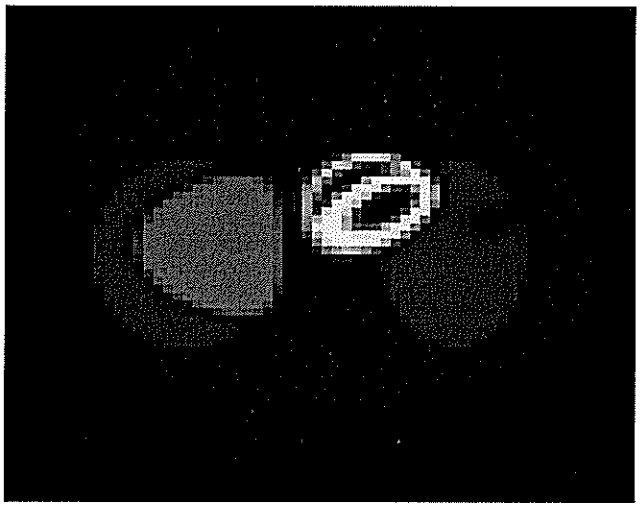
ITN	Summed	ML
16	20 (102)	0.3 (104)
32	23 (122)	1.1 (121)
64	23 (160)	1.1 (159)

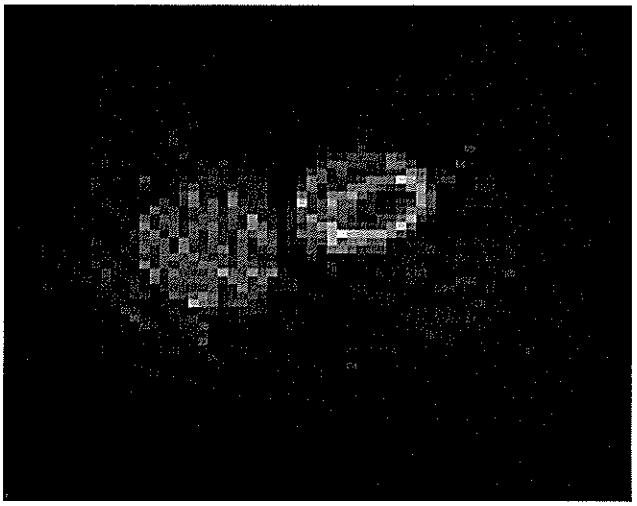
Errors in HROI

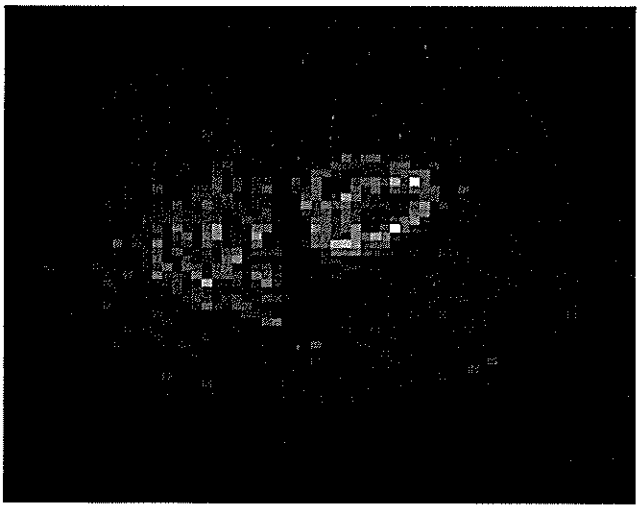
	Summed	ML
16	84 (257)	2.6 (260)
64	97 (305)	7.4 (319)

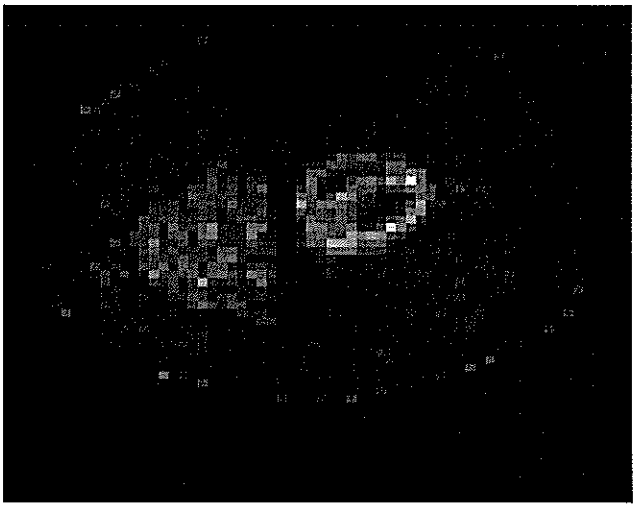
Visual comparisons

- [Image: recon.eps]
- [Image: dualEnergy/recon_180.eps]









Conclusion and Extensions

- Qualitative reconstruction/ quantitation
- Is there a bias in Summed reconstruction?
- Replication: single sample of noise, repeated pixels
- Interesting to extend to all 7 slices
- Effects of low vs high counts