Iterative reconstruction on Siemens CT scanners: noise, noise power spectrum, spatial resolution and low contrast detectability

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Outline

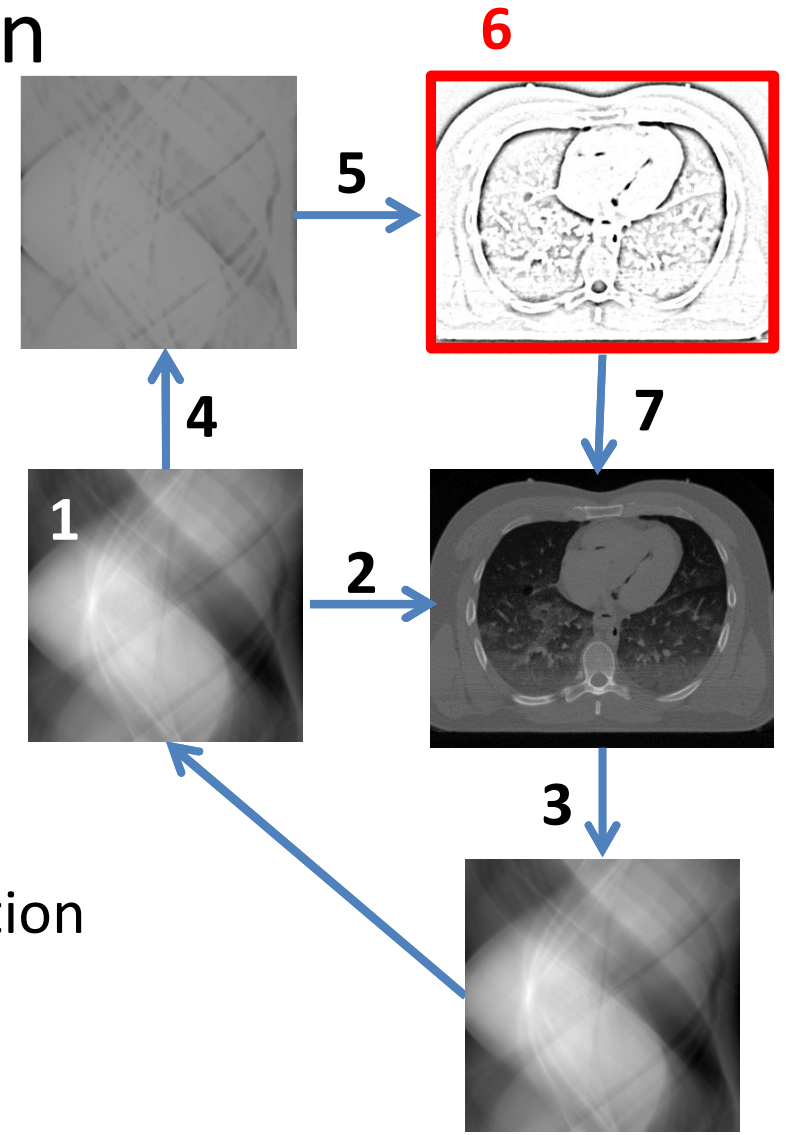
- Iterative reconstruction (IR) in CT
- Siemens IRIS and SAFIRE
- Testing methods
- Analysis
- Results
- Conclusion

Iterative reconstruction in CT

- Available now from more than one vendor
  - IRIS / SAFIRE (Siemens), ASIR / Veo (GE), iDose (Philips), AIDR (Toshiba)
  - Complementary to analytic method (FBP)
  - Can be implemented in range of ways
- Potential for
  - Noise reduction
  - Artefact reduction
  - Increased spatial resolution
- Downsides…
  - Huge computational cost
    - Practicality for clinical workflow?
  - Non linearity
    - Potential object dependent shift in CT numbers?

CT iterative reconstruction

- Familiar from nuclear medicine
  1. Acquire raw data
  2. Generate initial image (FBP)
  3. Forward project
  4. Calculate difference
  5. FBP for correction image
  6. Apply image regularization
  7. Correct image or raw data
  8. Repeat 3-8 as necessary
- Devil is in the detail and sophistication of implementation!



Siemens iterative CT: IRIS and SAFIRE

- IRIS – Iterative Reconstruction in Image Space
- SAFIRE – Sinogram AFfirmed Iterative REconstruction
- Specifics hard to discern in available literature!
- IRIS
  - All iteration done in image space (no projection to sinogram space)
  - Employ image regularisation to control noise
- SAFIRE
  - Employs forward projection and regularisation techniques
  - Potential for artefact reduction through 3D projection
- How they're used
  - Tick box to turn on, switch from Bxx -> Ixx or Hxx -> Jxx kernel
  - SAFIRE strength can be varied from 1-5

Testing methodology

- Look at image characteristics with and without IR
- Use clinical protocols and relevant phantoms
- Assess IQ metrics in same location where possible
  - Noise
  - Noise power spectrum (NPS)
  - Spatial Resolution
  - Also low contrast detectability (LCD) in Catphan
- Examine effect of acquisition and recon parameters on IQ for IR

Equipment

- Siemens Definition AS+ 128 with IRIS
- Siemens Definition AS 64 with SAFIRE
- Head and body water filled Perspex phantoms
- 100 mm Ø solid water insert, with 100 µm nickel wire

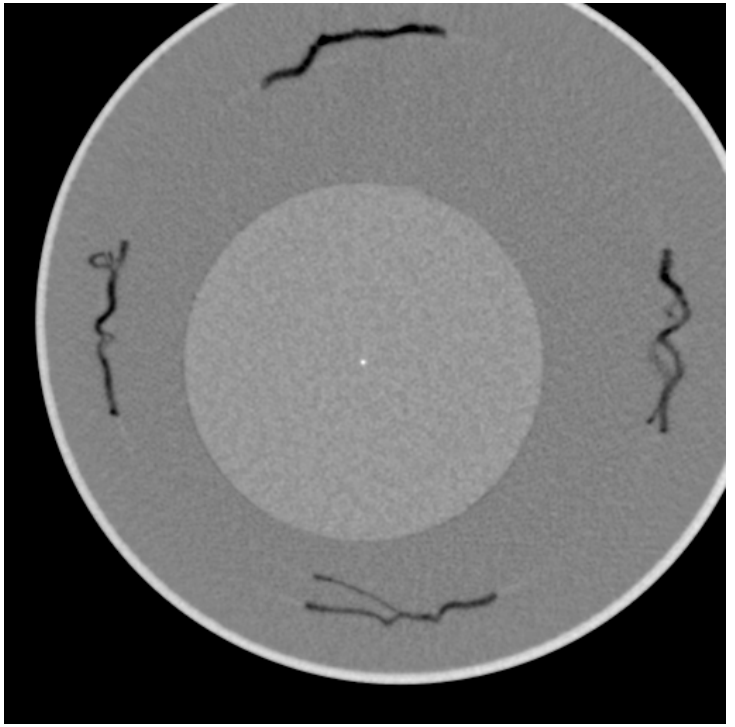
Scanning

- Standard abdomen and head protocols and variants

	Body	Head
Energy (kV)	120	120
Exposure (mAs)	210 and x 0.5, x 0.25 etc	410 / 370 and x 0.5, x 0.25 etc
t_{rot} (s)	0.5	1.0
pitch	0.6	0.55
data (mm)	128 / 64 x 0.6	128 / 64 x 0.6

• = Both scanners, • = IRIS, • = SAFIRE

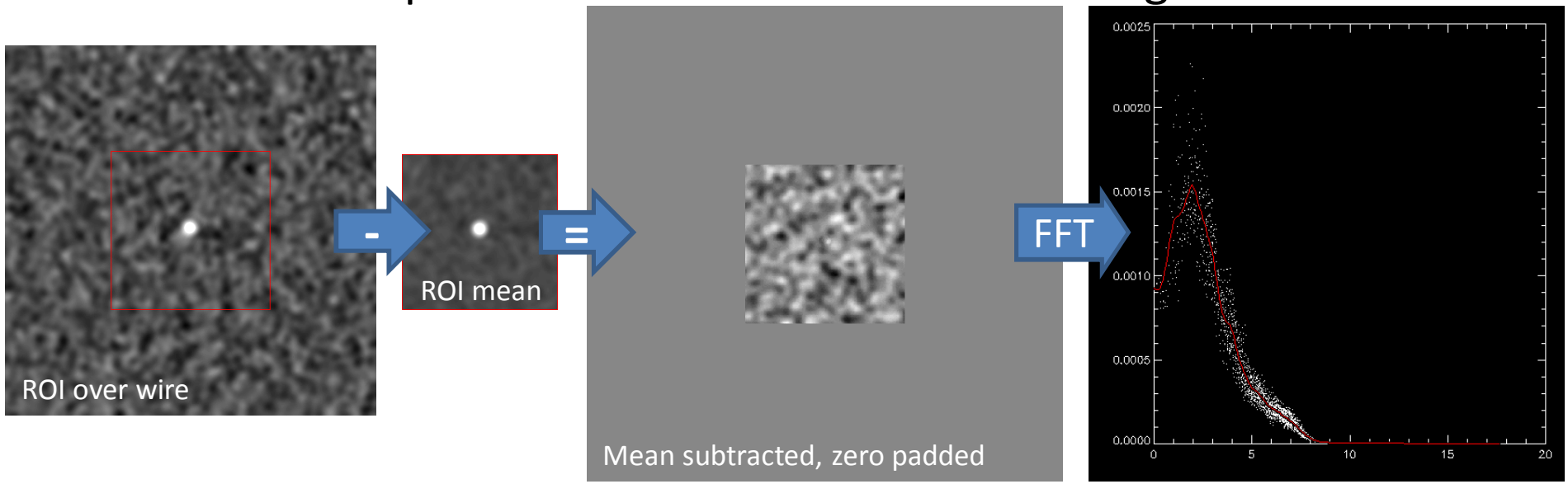
Analysis



- Phantom centred, wire ~20 mm off centre, recon centred on wire
- All IQ analysis in same location (within 25 mm of wire)
  - Minimise spatial variation of IQ
- Noise: SD of annulus around wire
  - inner Ø 10 mm, outer Ø 50 mm
- NPS: 21 x 21 mm region over wire
- Resolution: MTF of wire
- LCD: visual scoring of 3 and 5 HU details on Catphan
  - Contrast of 3, 5 and 10 HU details measured
- Results designed to be compared, not absolute

NPS analysis

- NPS calculated in ROI over wire
- Generate mean of 20 images over wire
- Subtract mean to remove wire
- Zero pad region to 3 x the size
- FFT for NPS, then take mean over 20 images
- Results compare well to those from uniform region



Results: noise (1)

- $SD_{IR\ On}$ / $SD_{IR\ Off}$ at standard protocols

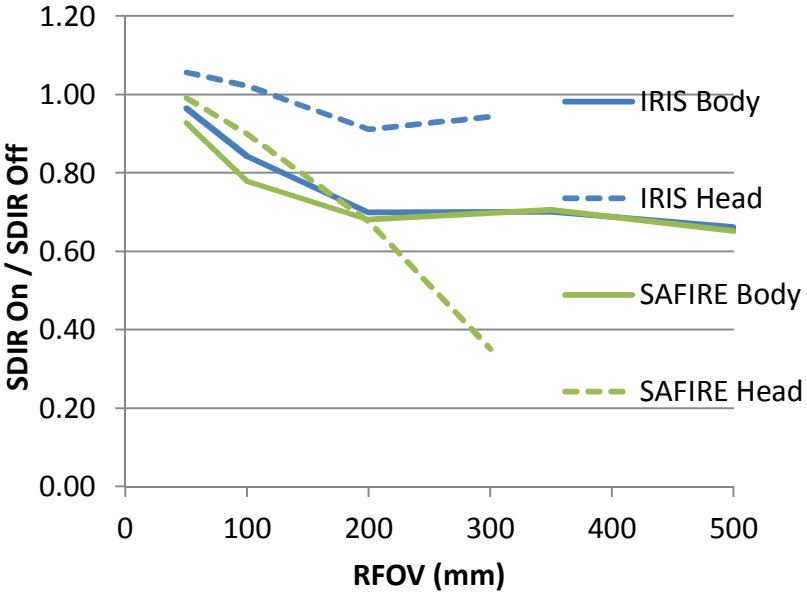
	IRIS	SAFIRE*
Body	0.70	0.71
Head	0.91	0.68
* SAFIRE level 3 is standard in this study		

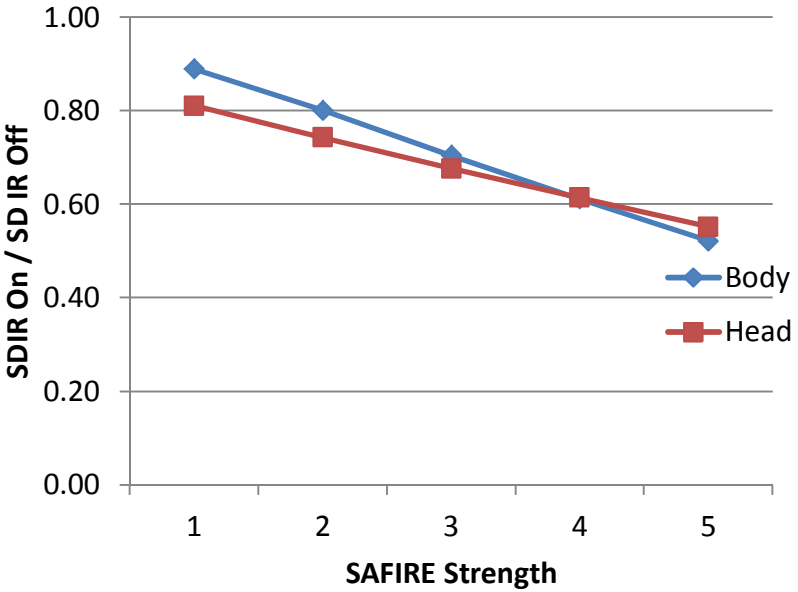
- Same ratio at 1/2 , 1/4 , or 1/8 mAs
- Sharper kernel -> more noise reduction
  - e.g. $SD_{IR\ On}$ / $SD_{IR\ Off}$ for IRIS head

Kernel	Ratio SD_{Jxx} / SD_{Hxx}
J30 / H30	0.91
J45 / H45	0.80
J70 / H70	0.61

Results: noise (2)

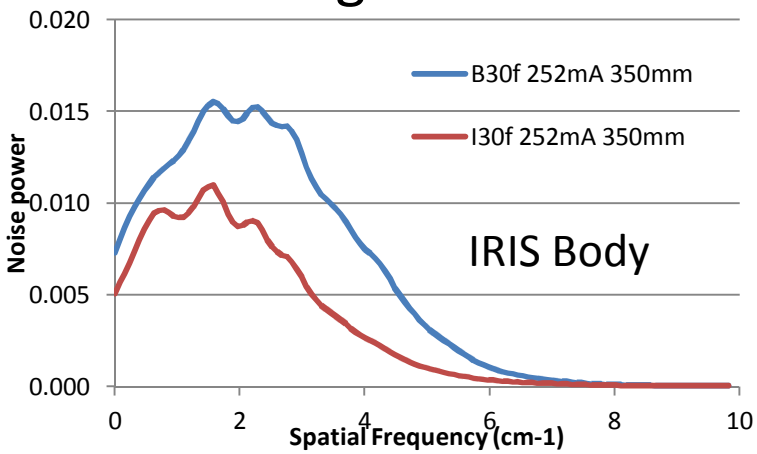
- Main dependent variable is RFOV
- SAFIRE strength also affects noise ratio

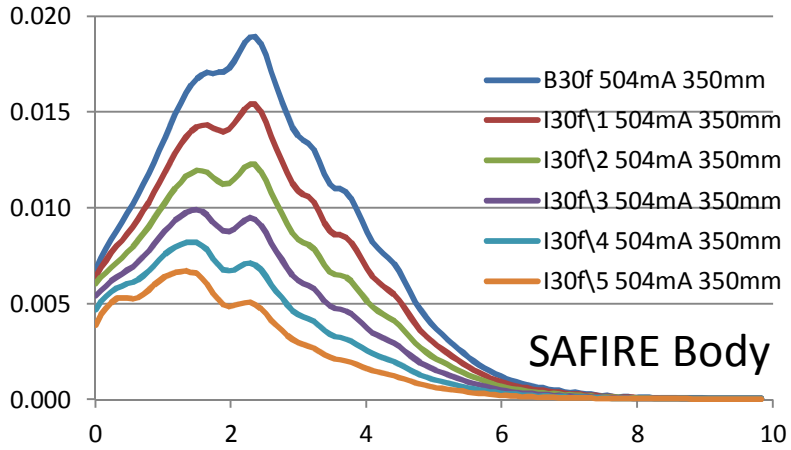


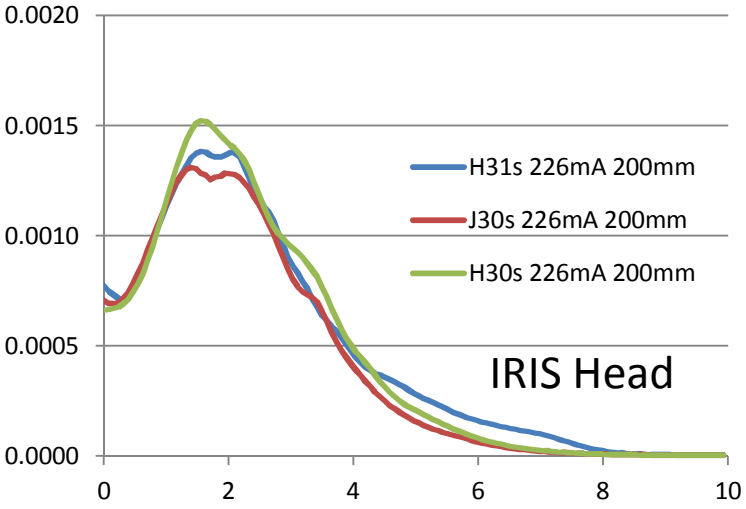


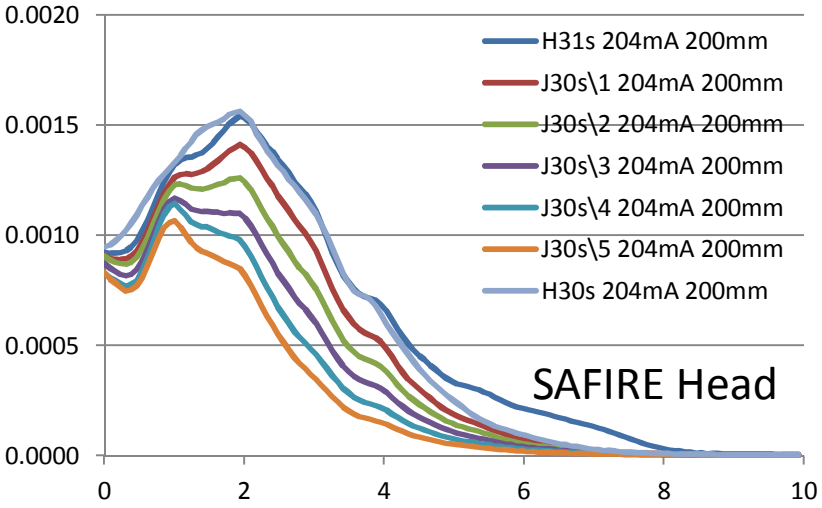
Results: NPS (1)

- NPS changes reflect reduced noise for IR



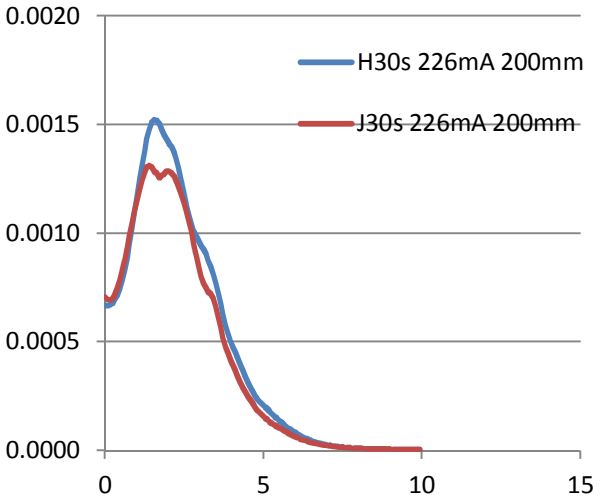




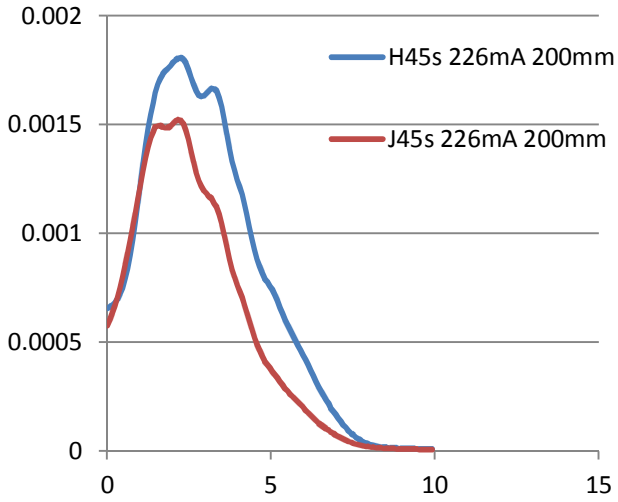


Results: NPS (2)

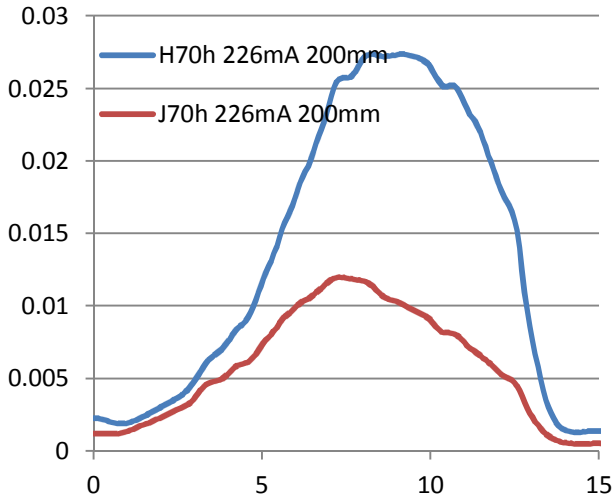
- NPS effect with kernel, and std deviation values (IRIS head)



J30 / H30 : 0.91
H30 : 5.5
J30 : 5.0



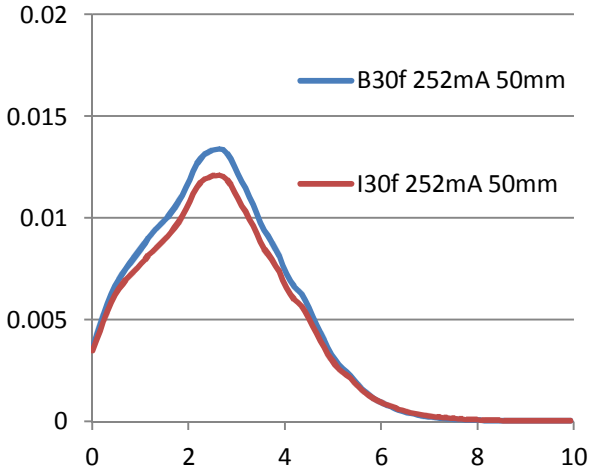
J45 / H45 : 0.80
H45 : 6.1
J45 : 7.7

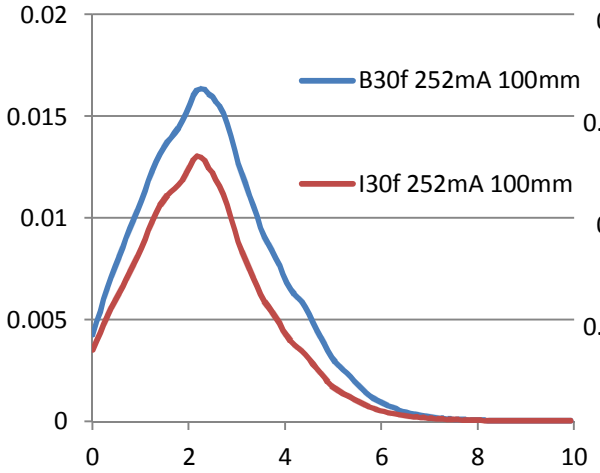


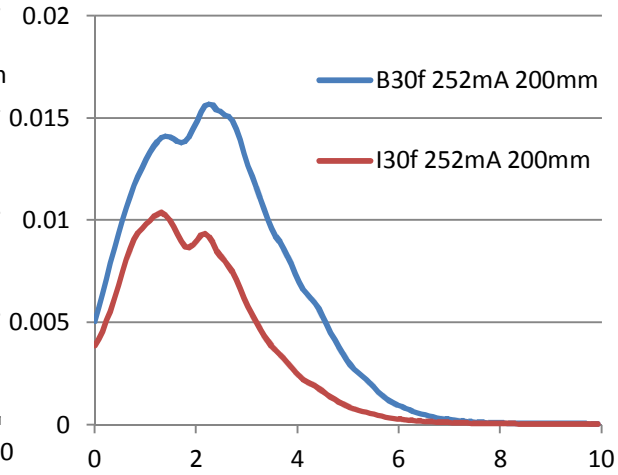
J70 / H70 : 0.61
H70 : 66
J70 : 40

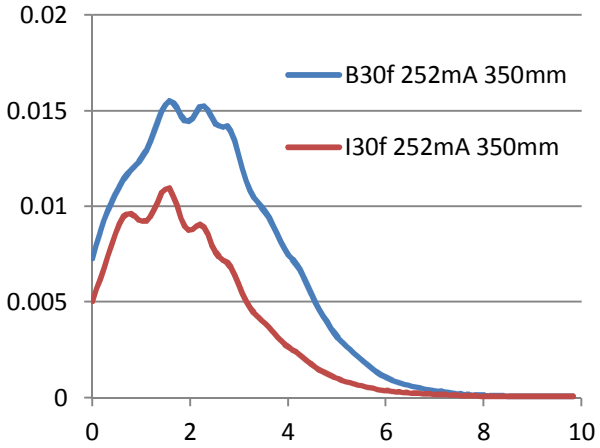
Results: NPS (3)

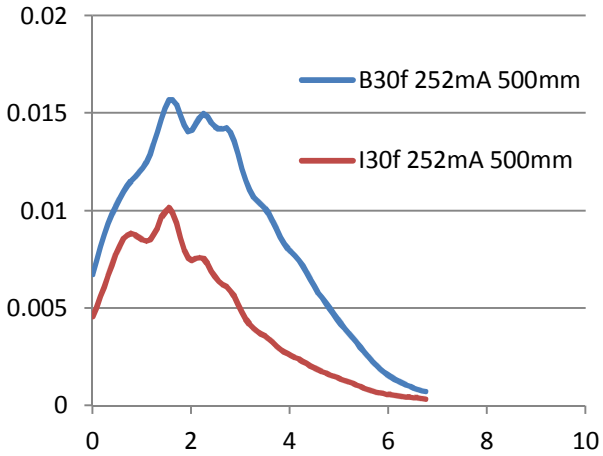
- NPS effect with RFOV (IRIS body)







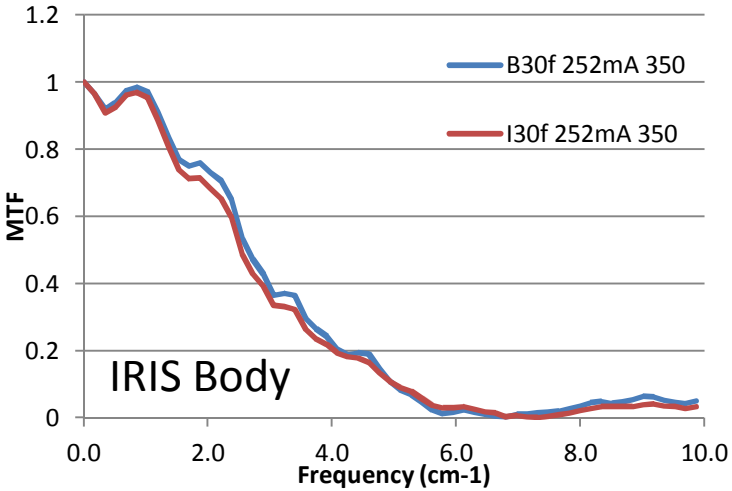


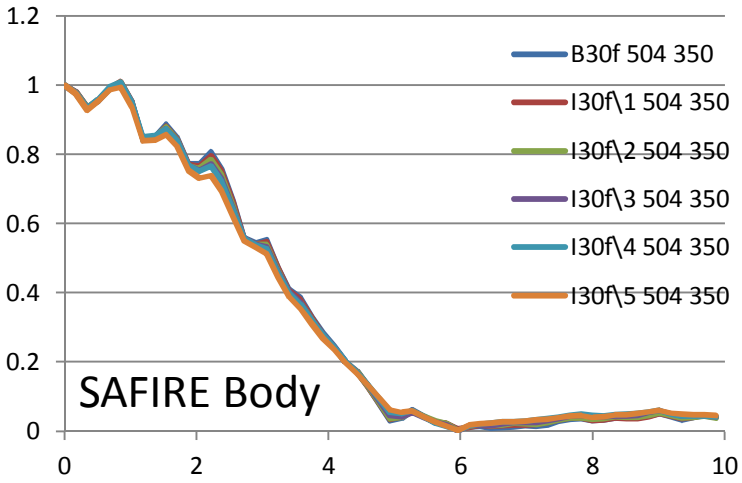


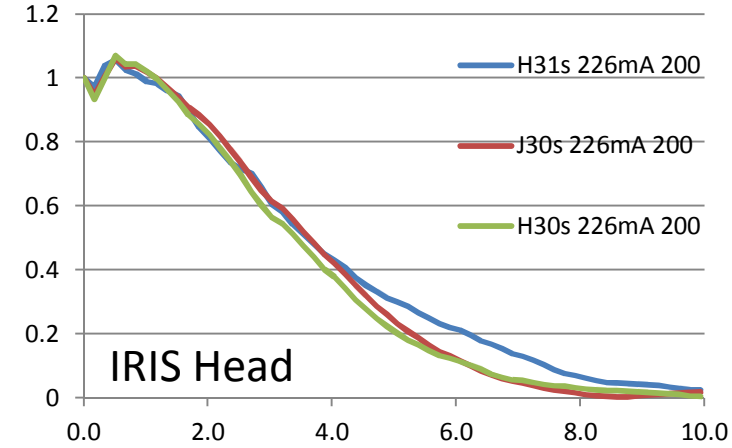
RFOV (mm)	SD_{I30} / SD_{B30}
50	0.96
100	0.84
200	0.70
350	0.70
500	0.66

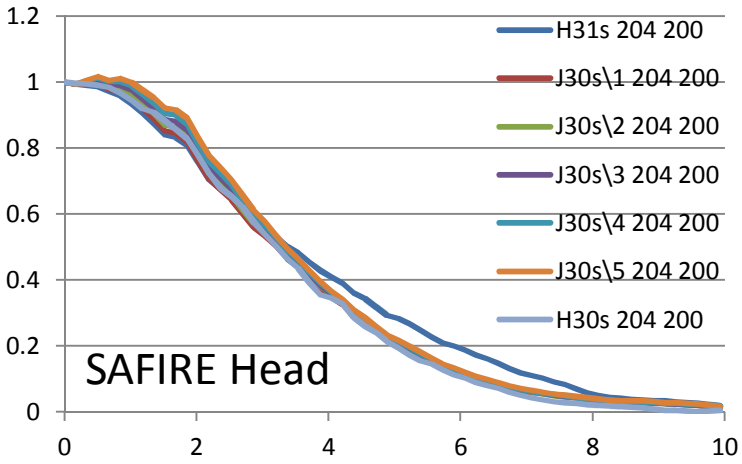
Results: resolution (1)

- No significant change with IR!



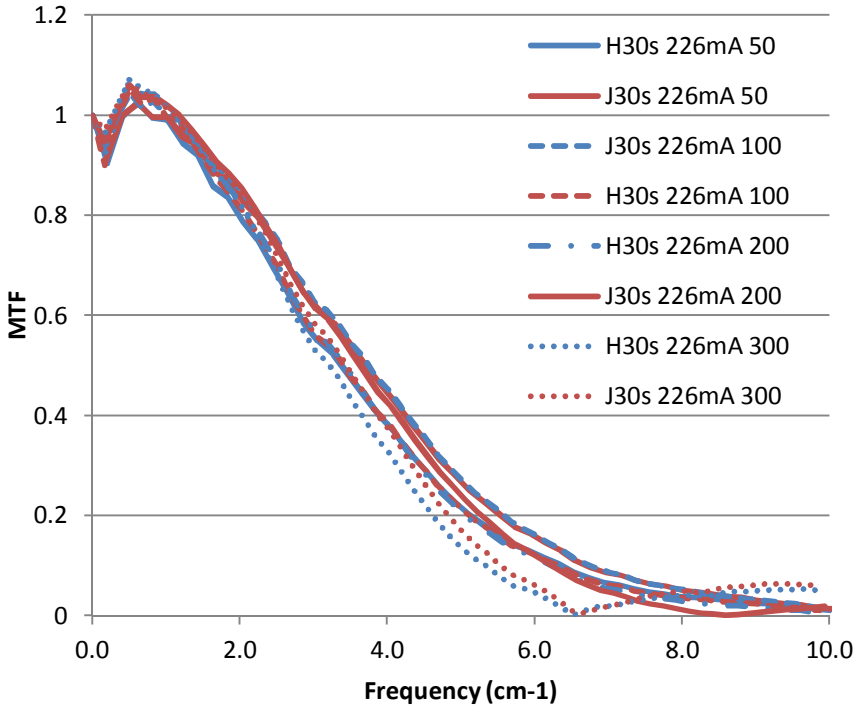


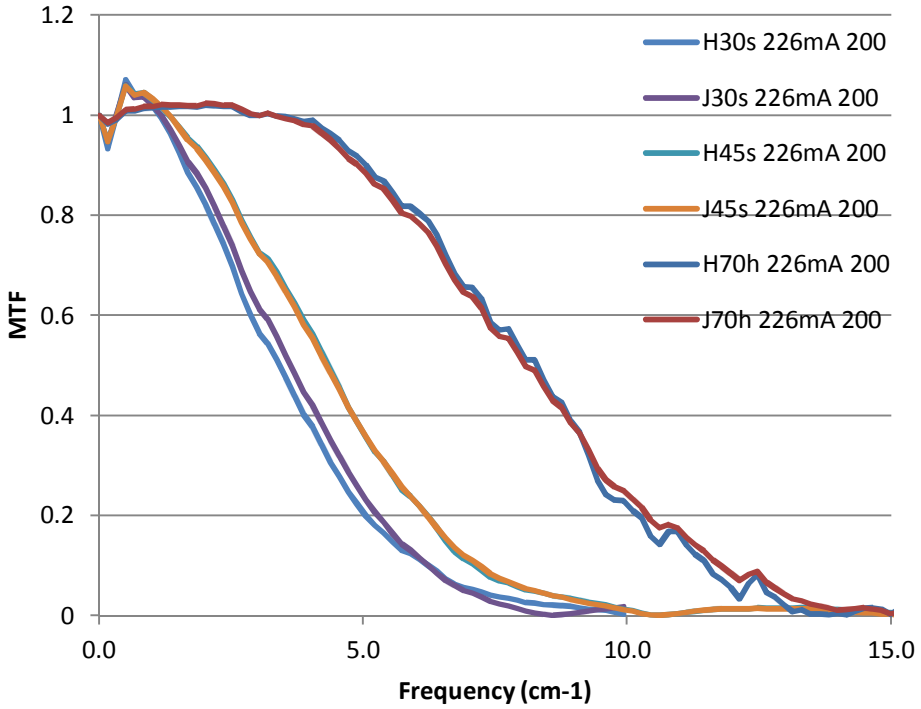




Results: resolution (1)

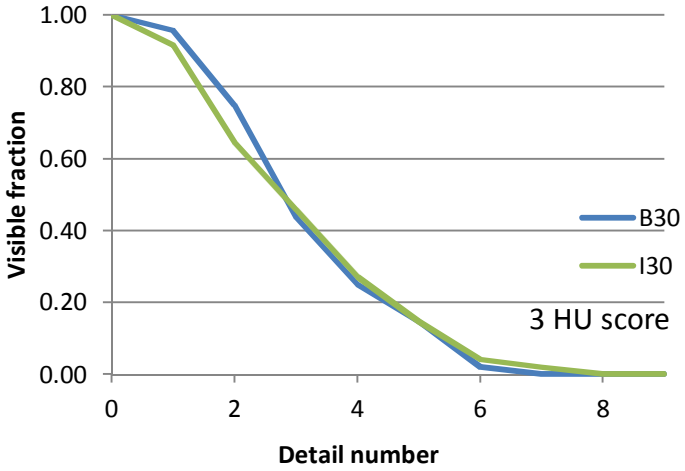
- Effect of FOV and kernel (IRIS head)

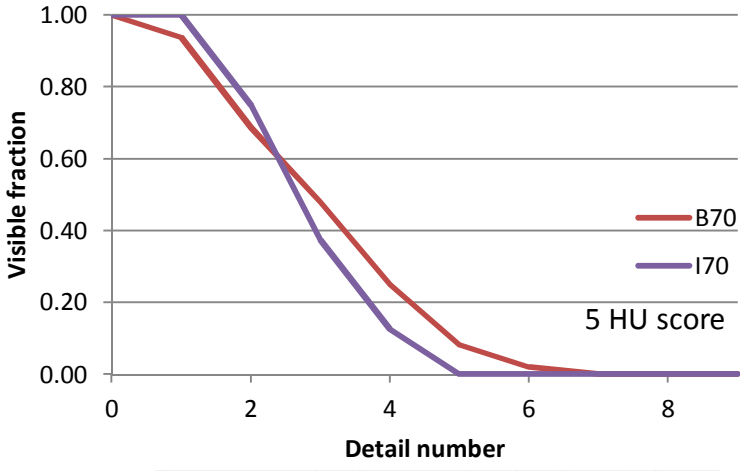


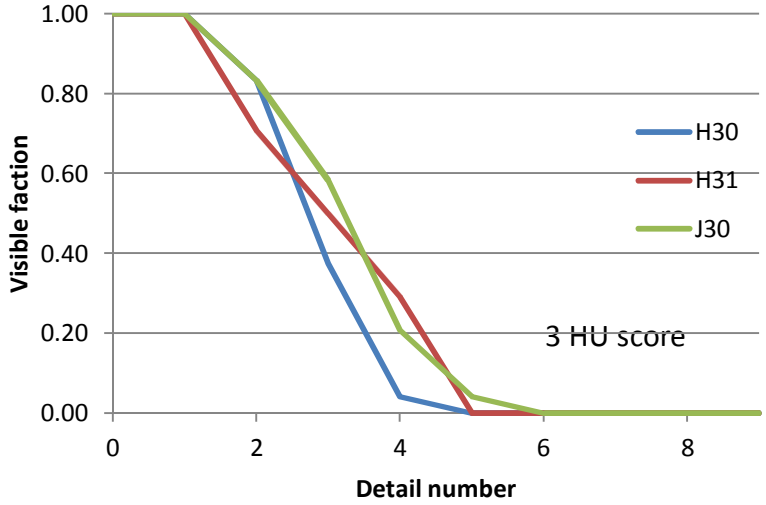


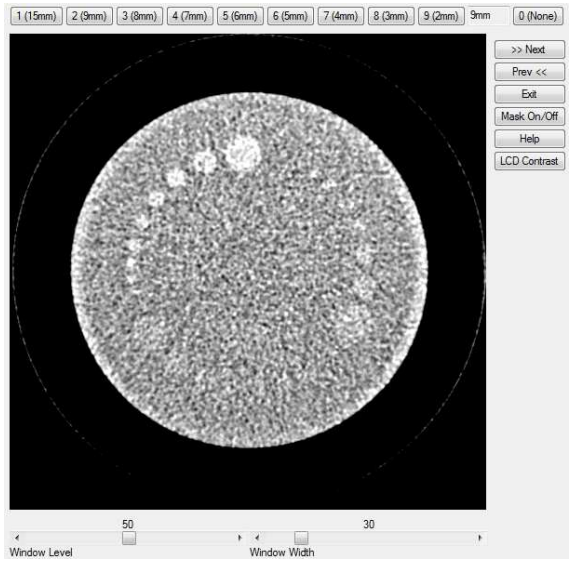
Results: LCD

- Early results from IRIS LCD testing – 2 observers, 1 dose level









Conclusions

- Siemens' IR algorithms reduce image noise relative to FBP
  - Seen in standard deviation and noise power spectrum
  - Effect independent of mA
  - Effect greater at large RFOV
  - Effect greater for higher SAFIRE strength
- This is achieved without loss of spatial resolution
- Little effect seen in early Catphan results
  - IRIS results only so far
  - Needs more observers / range of exposure conditions

Thanks:

- CT department, Hammersmith Hospital
  - IRIS scanning
- CT department, Chelsea and Westminster Hospital
  - SAFIRE scanning
- ImPACT for loan of wire phantom

Image noise, IR_{on} / IR_{off}

	IRIS body	IRIS head	SAFIRE body	SAFIRE head
Std	0.70	0.91	0.71	0.68
mAs ~ x 1/2	0.70	0.92	0.71	0.70
mAs ~ x 1/4	0.72	0.90	0.71	0.70
B70 or H70 kernel	0.59	0.61	0.65	0.62
50 mm RFOV	0.96	1.06	0.93	0.99
100 mm RFOV	0.84	1.02	0.78	0.90
200 mm RFOV	0.70	0.91	0.68	0.68
350/300 mm RFOV	0.70	0.94	0.71	0.35
500 mm RFOV	0.66		0.65	