Optimisation of CT radiation dose in PET/CT imaging using mA modulation and iterative reconstruction

CTUG Meeting

16th October 2014

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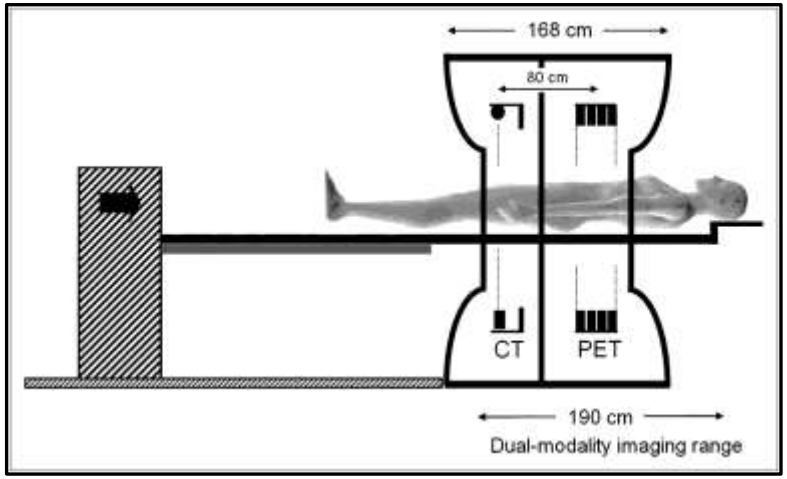
Introduction

CT in PET-CT

- Patients administered with tracer compound labelled with positron emitting radionuclide i.e. ^{18}F-FDG
- Uptake period of 90 minutes in holding bay
- Patient has half-body CT scan (<1 minute) followed by half-body PET imaging (3 min/bed position ~ 21 minutes)



Dispensing PET tracer

Patient Administration and Uptake

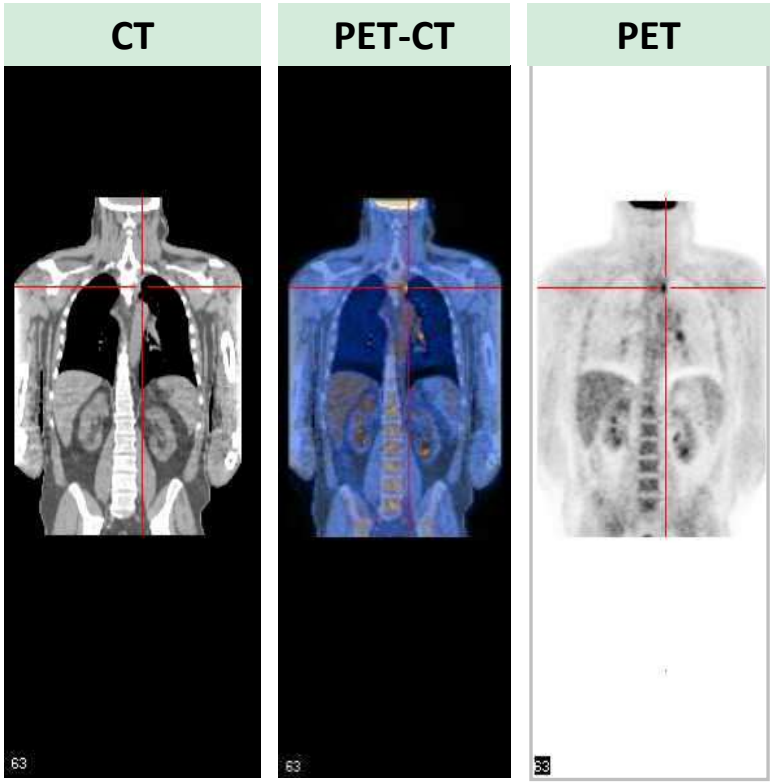
PET-CT Scanning

Introduction

CT in PET-CT

CT Protocol	
mA	115
Rotation Speed	0.5s
Pitch	1.375
Collimation	16 x 2.5mm
$CTDI_{vol}$	5.2mGy

CT Radiation dose = 7mSv



PET Protocol	
ARSAC Diagnostic Reference Level (DRL) ^{18}F-FDG	400MBq
Effective Dose 400MBq ^{18}F-FDG	8mSv

PET Radiation dose for 350MBq ^{18}F-FDG= 7mSv

Introduction

Aims

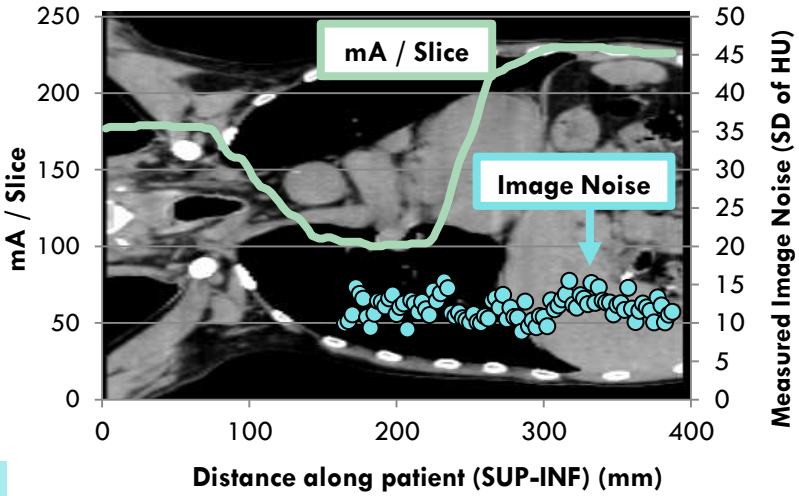
King's College London & Guy's and St Thomas' PET Centre

- PET Imaging Centre at St. Thomas' Hospital moved to new area in hospital in Oct 2013
- 2 x GE Discovery 710 PET-CT scanners (Optima 660 CT component)
- New scanners have mA modulation and statistical iterative reconstruction
- For optimisation of PET and CT protocols, institutional ethical approval obtained to perform patient local views on new scanners with patients receiving no additional radiation dose;

Introduction

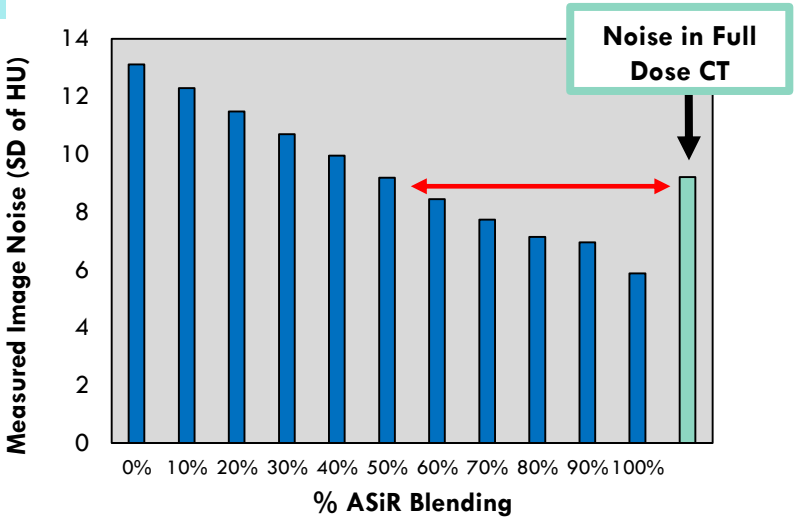
GE Smart mA

- CT tube current varies rotationally and longitudinally as patient is scanned to maintain image noise constant
- Parameters to set are minimum mA, maximum mA and Noise Index



GE ASiR (Adaptive Statistical Iterative Reconstruction)

- System noise statistics model applied to original projection data; Noise propagated through to iteratively reduce noise in reconstructed images.
- Statistical reconstruction is blended to various degrees with the original FBP reconstruction. GE recommend a setting of 40% ASiR blending, which theoretically enables a 40% dose reduction with no change in image noise.



Variation of measured image noise in water with % ASiR for a 50% reduced dose CT

Methodology

A: Local view CT scans to determine optimum Noise Index (NI)

Patient local views (N=13) were scanned with the NI set to obtain a $CTDI_{vol}$ value 50% that of the current protocol. All images were reconstructed using 40% ASiR.

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B. Clinician review of Low Dose Scans

CT local views stored alongside several full dose FBP only CT images of patients of matched size and appearance. Images were scored blindly for image quality by 3 PET/CT clinicians, using scoring scale:

1 = non-diagnostic or unacceptable
2 = diagnostic but sub-optimal
3 = satisfactory
4 = good
5 = excellent

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C: Proposed protocol

The results from Part A and Part B were used to define a reduced dose CT protocol, and an additional 7 patients were scanned.

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D: Evaluation of Final Images

The local views obtained in Part C were reviewed again by clinicians to assess the proposed protocol. Any variations/changes to the proposed protocol were discussed.

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E: Clinical Implementation of New Protocol

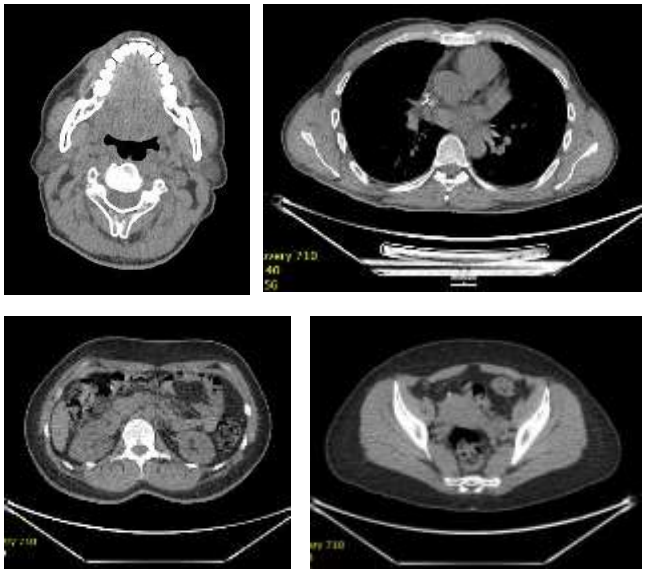
Scanning protocols changed on scanner. New temporary DRLs were set and staff received training in mA modulation/patient centering prior to first patient scans using new protocol.

Results

Clinician Scoring of Part A Images

	Clinician A	Clinician B	Clinician C
Head and Neck 1	4	3	3
Head and Neck 2	4	3	4
Chest 1	4	4	5
Chest 2	5	4	3
Chest 3	3	3	2
Chest 4	3	2	3
Abdo 1	5	4	4
Abdo 2	4	3	3
Pelvis 1	4	3	2
Pelvis 2	5	3	3
Pelvis 3	4	2	3
Pelvis 4	4	3	4

Scoring Scale	
1	Non-diagnostic or unacceptable
2	Diagnostic but sub-optimal
3	Satisfactory
4	Good
5	Excellent



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Abdo 2	4	3	3
Pelvis 1	4	3	2
Pelvis 2	5	3	3
Pelvis 3	4	2	3
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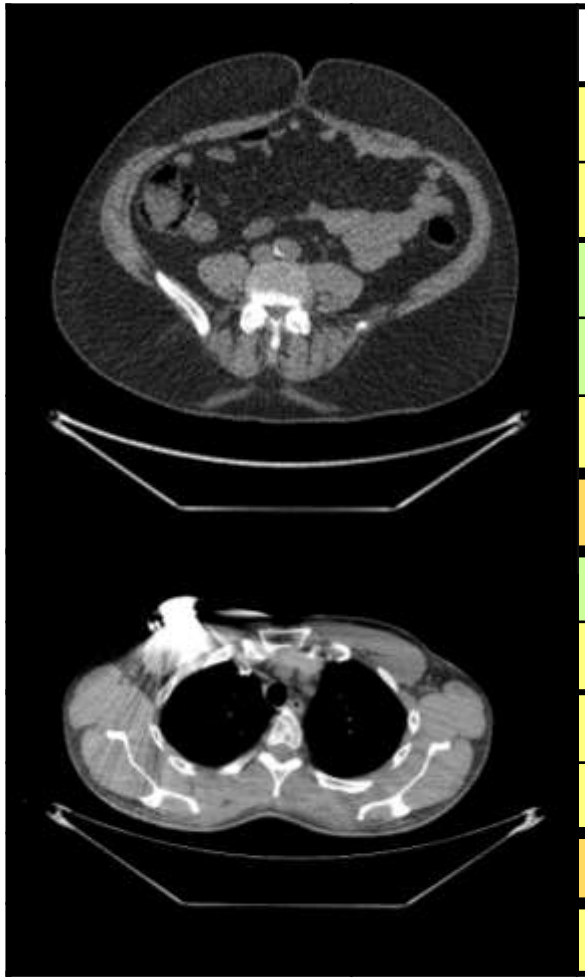
- None of the Part A local view images scanned at 50% dose were deemed **'non-diagnostic or unacceptable'**

- **Weighted Kappa Test:**
  - Fair correlation between Clinician A and Clinician B,
  - Fair correlation between Clinician B and Clinician C
  - No correlation between Clinician A and Clinician C.

Results

Clinician Scoring of Part A Images



Clinician B	Clinician C
3	3
3	4
4	5
4	3
3	**2**
2	3
4	4
3	3
3	**2**
3	3
2	3
3	4

Scoring Scale	
1	Non-diagnostic or unacceptable
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- **Diagnostic but sub-optimal**: patients scanned with arms down, pacemaker artefacts, large patients

Results

Clinician Scoring of Part A Images

- ‘Matched’ CT images

	Clinician A Scores		Clinician B Scores		Clinician C Scores	
	Full Dose	50% Dose	Full Dose	50% Dose	Full Dose	50% Dose
Chest	4	4	5	4	5	5
Abdo	4	4	4	3	3	3
Pelvis	4	4	4	4	4	4
Head and Neck a)	4	4	4	3	4	3
Head and Neck b)	4	4	4	3	5	4

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1	Non-diagnostic or unacceptable
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Full Dose

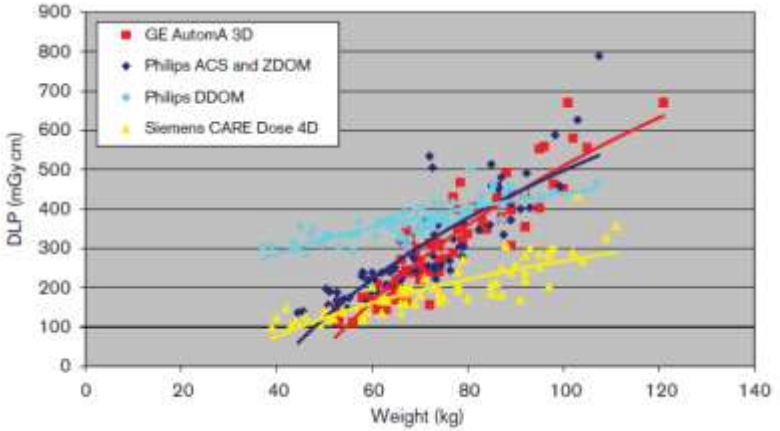
50% Dose

Results

Proposed Protocol: Torso

- Mean GE Noise Index (NI) 50% dose reduction was **41** (1 S.D. = 6, Range 34 – 52)
- Proposed protocol:

Noise Index	40
Minimum mA	15
Maximum mA	100
Acquired Slice Thickness	2.5mm
Reconstruction	Std/40% ASiR



G Iball and D Tout, *Computed Tomography Automated Exposure Control Techniques in ^{18}F-FDG Oncology PET-CT Scanning*, Nuc Med Comm 2014, Vol 35 No 4

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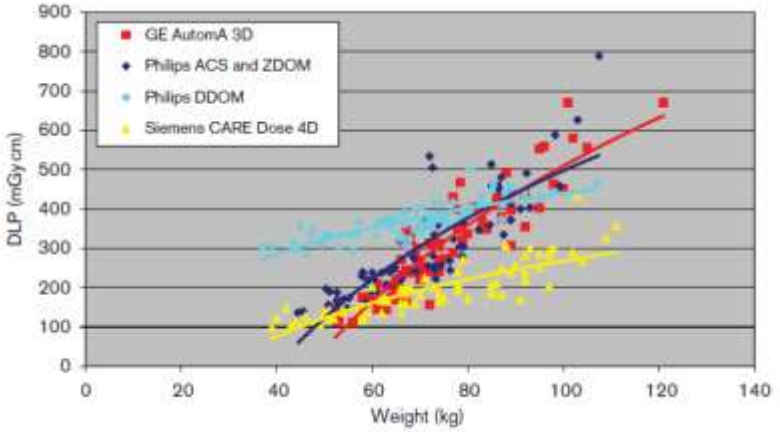

- Protocol was tested on scanners without scanning for a selection of 11 patients. The mean displayed $CTDI_{vol}$ (2.9mGy) represented a 45% dose reduction compared to the current fixed mAs protocol; mA saturated at 100mA for 8/11 patients;

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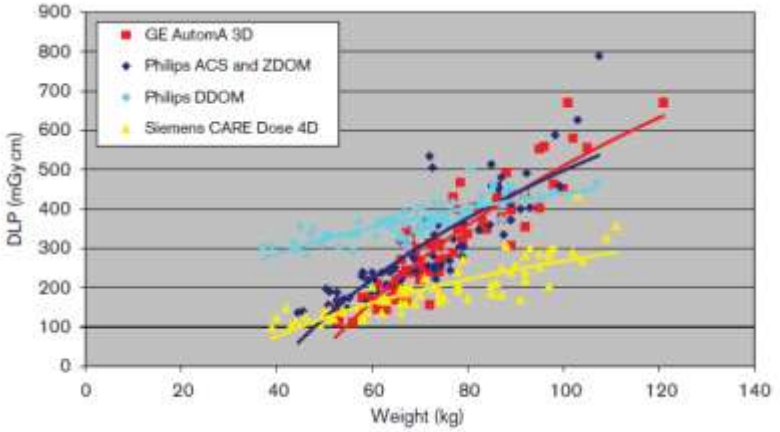

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- For remaining 4 torso local view patients, small patients (<50kg) were scanned.
- In evaluation of the final images, clinicians were satisfied with the image quality and therefore one protocol used for all patient sizes.

Results

Proposed Protocol: Head and Neck

- Head and neck region represents a challenge to mA modulation.

Full Dose

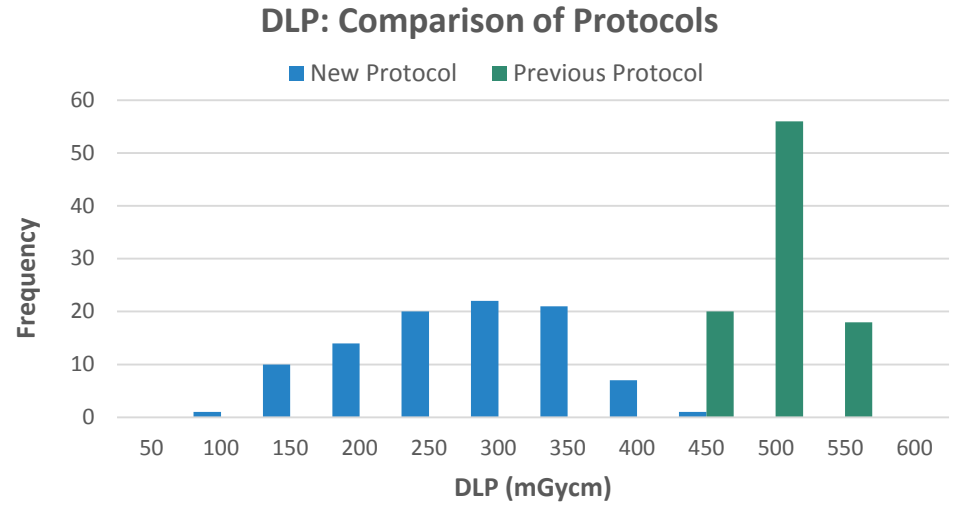
50% Dose

- As 2/3 clinicians scored the reduced dose head and neck image quality down in the initial images, in second group of scans the Noise Index and minimum mA were varied to improve image quality.

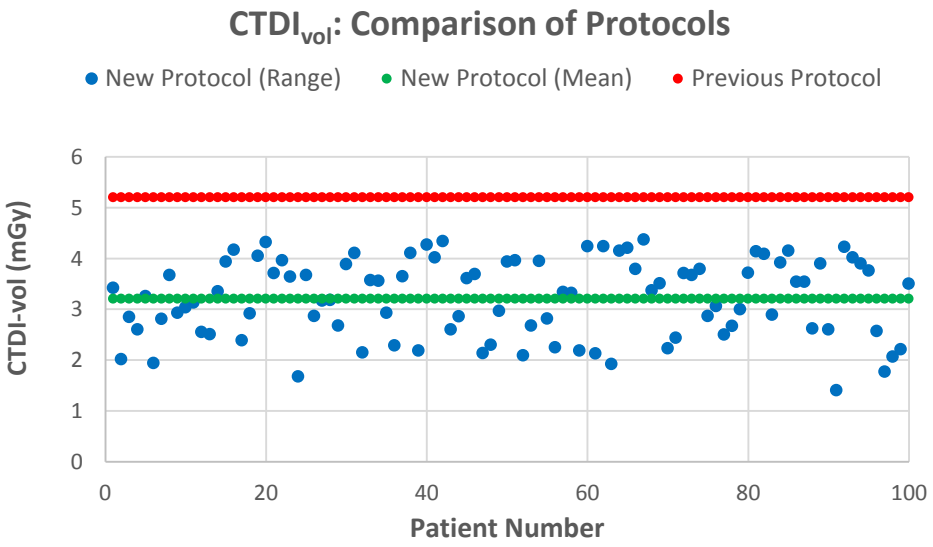
- In clinician review of the final images, it was concluded that the mA modulation ASiR protocol would not be implemented for these scans.

Results

Dose Reduction of New Protocol



	Old Protocol	New Protocol
	DLP (mGycm)	DLP(mGycm)
Mean	486	302
Std Dev	64	77
Max	852	467
Min	416	114
Third Quartile	479	363
Mean Dose Reduction (range)	38% (4% - 77%)	



	Old Protocol	New Protocol
	$CTDI_{vol}$ (mGy)	$CTDI_{vol}$ (mGy)
Mean	5.2	3.2
Std Dev	----	0.8
Max	----	4.4
Min	----	1.4
Third Quartile	----	3.9
Mean Dose Reduction (range)	38% (15% - 73%)	

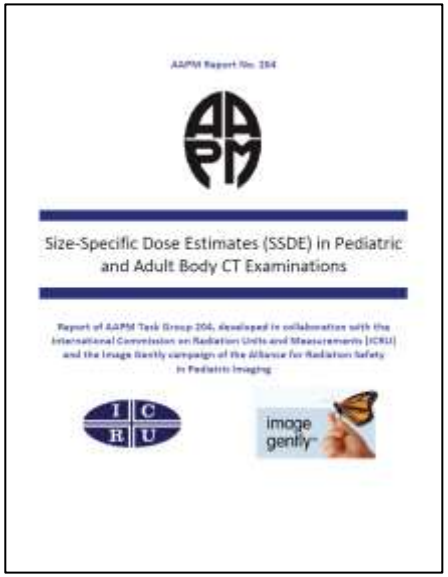
National CT DRLs (2011) for chest abdo pelvis $CTDI_{vol}$= 13mGy. Therefore PET-CT DRL is ⅓ of diagnostic value.

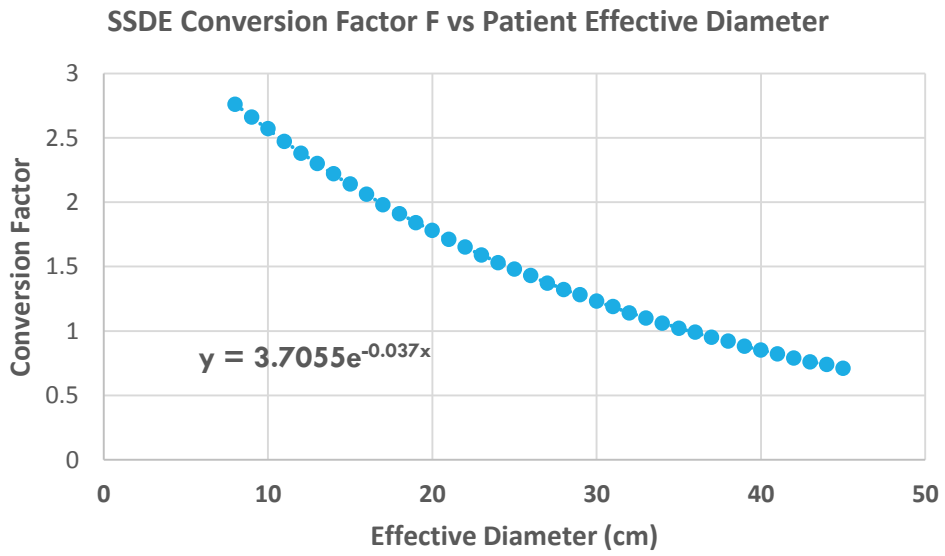
Results

Dose Reduction of New Protocol

- Dose received by a patient from a CT scan is dependent on both patient size and scanner radiation output. $CTDI_{vol}$ provides information regarding only the scanner output so does not estimate radiation dose.
- US task group 204 developed conversion factors that can be applied to displayed $CTDI_{vol}$ to allow estimation of radiation dose for various size patients.

Size Specific Dose Estimate (SSDE) = $CTDI_{vol}$ x F





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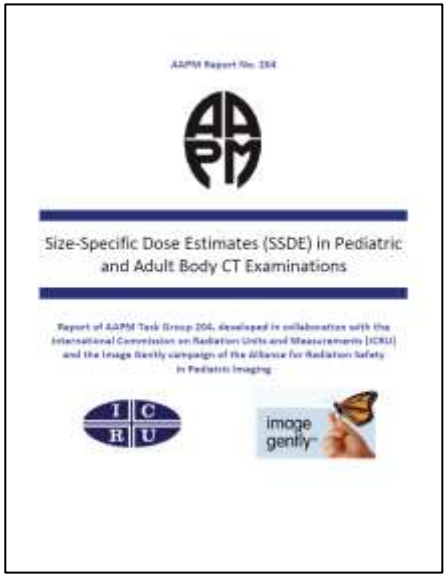
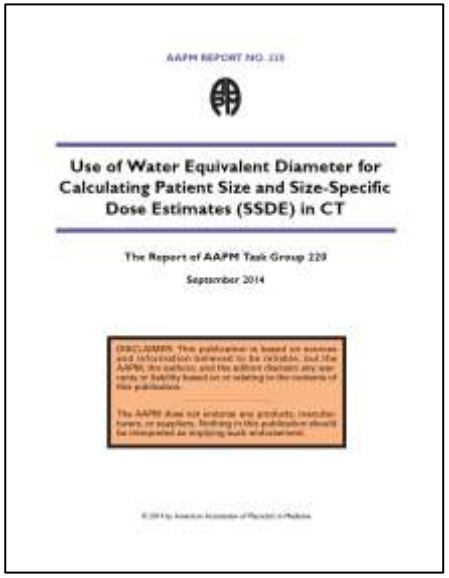
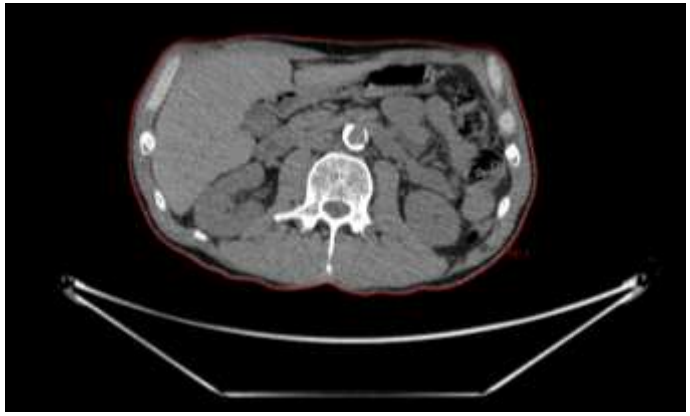




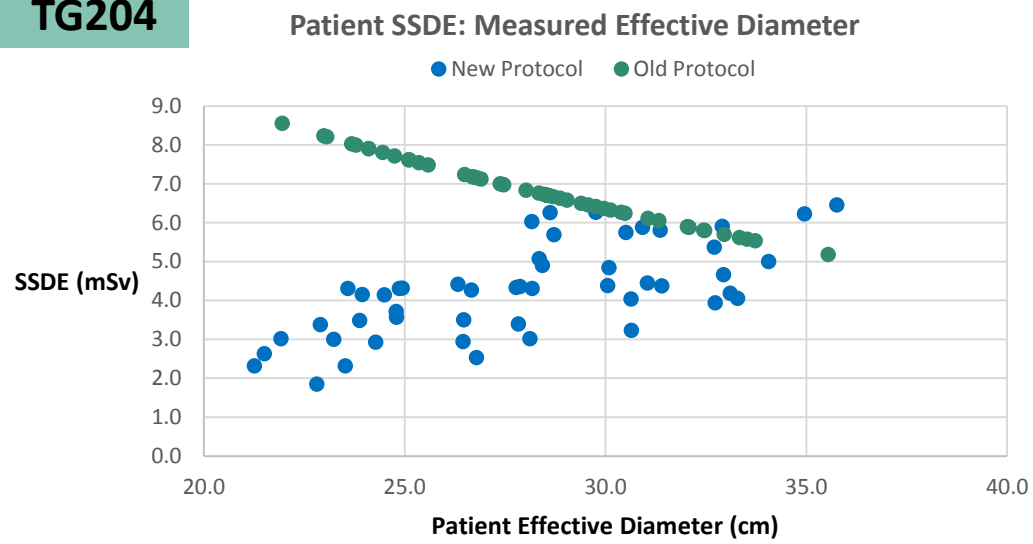


$$D_w = 2\sqrt{\left[\frac{1}{1000}\overline{CT(x,y)_{ROI}} + 1\right]\frac{A_{ROI}}{\pi}}$$

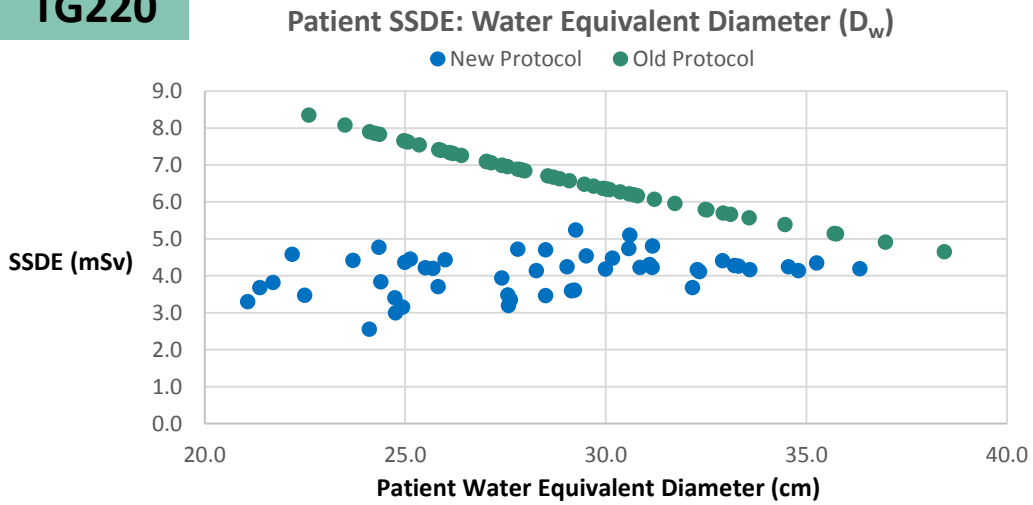
Results

Dose Reduction of New Protocol

TG204



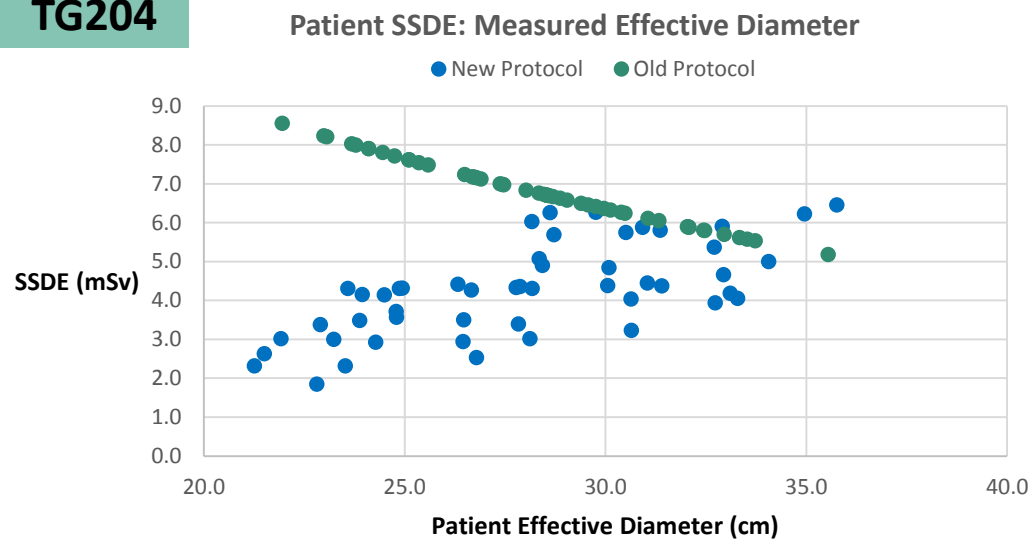
TG220



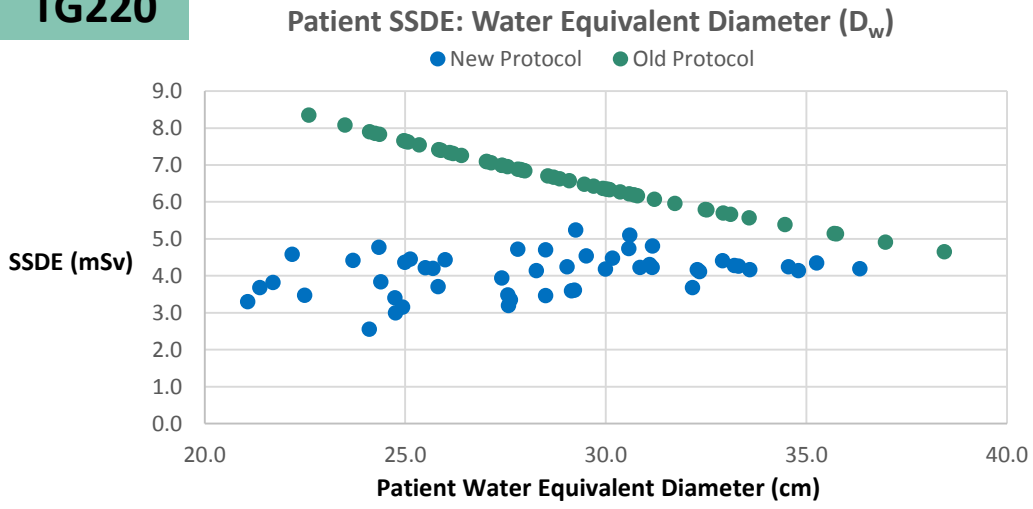
Results

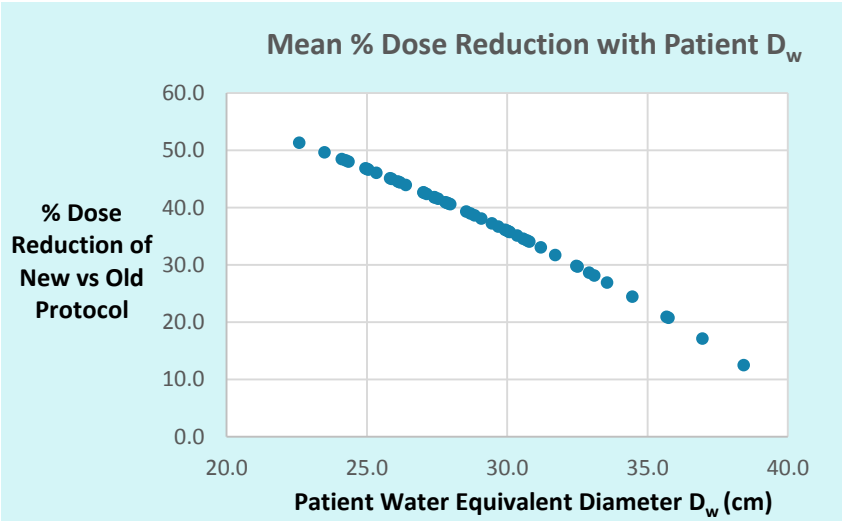
Dose Reduction of New Protocol

TG204



TG220

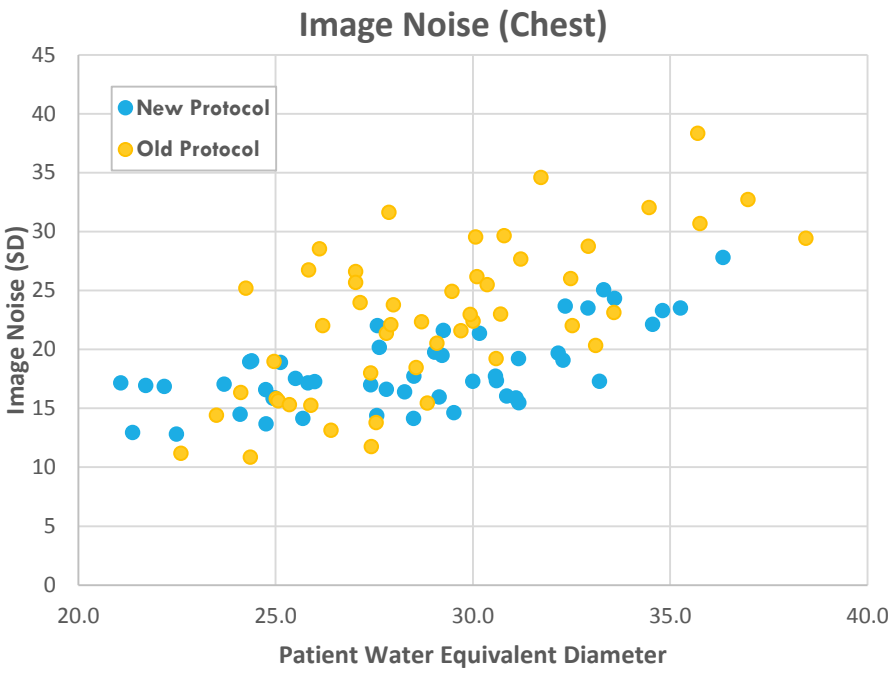




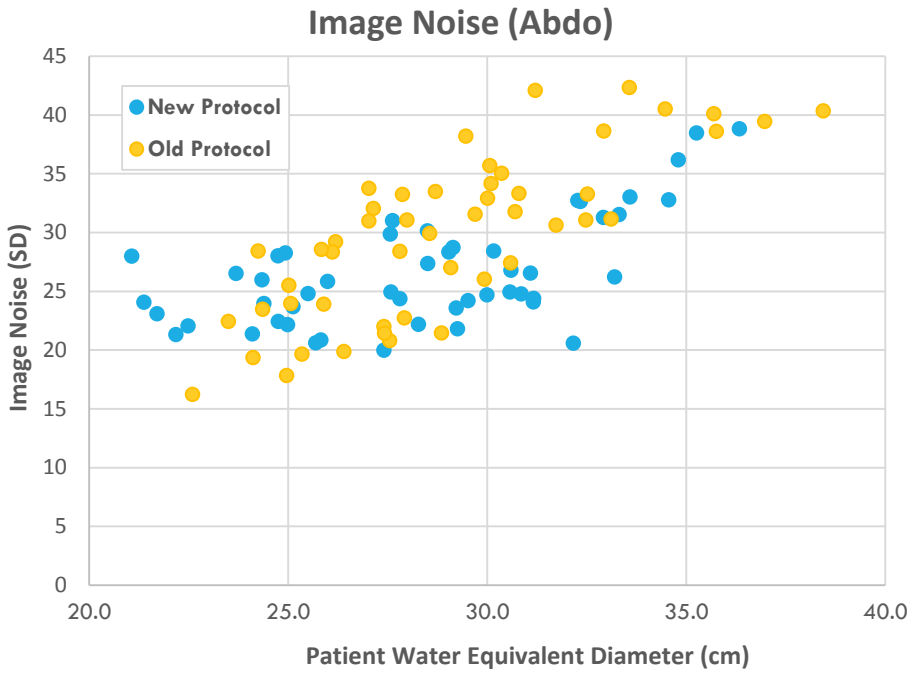
- With new protocol, doses for small patients are decreased the most

Results

Image Quality of New Protocol



	Mean Noise + S.D
New Protocol	19.1 +/- 3.6
Old Protocol	22.7 +/- 6.5



	Mean Noise + S.D
New Protocol	27.1 +/- 4.7
Old Protocol	29.8 +/- 6.9

- Difference in noise measurements between old and new protocols is statistically significant ($p<0.05$)

Results

Protocol for arms up/arms down

Patient Dose	Mean DLP (1 S.D.)		Mean $CTDI_{vol}$ (1 S.D.)	
	Patient Arms Up	Patient Arms Down	Patient Arms Up	Patient Arms Down
Old Protocol	487 (65)	486 (65)	5.2 (0.0)	5.2 (0.0)
New Protocol	296 (79)	307 (76)	3.1 (0.8)	3.3 (0.7)

- Difference in dose metrics for arms up/arms down is not statistically significant (p=0.477 (DLP) /0.463 ($CTDI_{vol}$))

Results

Phase 2: Head and Neck Local Views

Results

Phase 2: Head and Neck Local Views

- An additional 5 patients had reduced dose head and neck local views (mA = 70, 40% ASiR reconstruction)
- Images scored by clinicians

	Clinician 2		Clinician 3	
	Full Dose (FBP)	40% Dose + 40% ASiR	Full Dose (FBP)	40% Dose + 40% ASiR
Head and Neck 1	4	4	5	5
Head and Neck 2	4	3	3	4
Head and Neck 3	3	3	5	4
Head and Neck 4	4	3	5	4
Head and Neck 5	4	4	4	3

Scoring Scale	
1	Non-diagnostic or unacceptable
2	Diagnostic but sub-optimal
3	Satisfactory
4	Good
5	Excellent

Discussion

How do CT doses compare with other PET-CT Sites?

	Mean DLP (mGycm)	Mean Image Noise (HU)	Slice Thickness (mm)
St Thomas' PET Centre	302	27.1	2.5
Manchester/Leeds PET-CT 1 (GE)	306	22.4	3.75
Manchester/Leeds PET-CT 2 (Siemens)	197	42.1	4
Manchester/Leeds PET-CT 3 (Philips)	385	15.2	4
Manchester/Leeds PET-CT 4 (Philips)	296	19.7	4

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CT for PET Attenuation Correction?

mAs	Activity Concentration (Bq/ml)
10	5767
15	5769
20	5769
25	5759
30	5762
35	5763
40	5763

Conclusions

- Mean effective half-body CT dose in PET-CT reduced to 4.2mSv. Therefore CT component is now ~38% of total PET-CT dose.
- Image Quality has received no complaints. Image noise measured in torso is lower than previous protocol.
- Possibility of reduction of mean effective head and neck CT dose from 1mSv to 0.6mSv.

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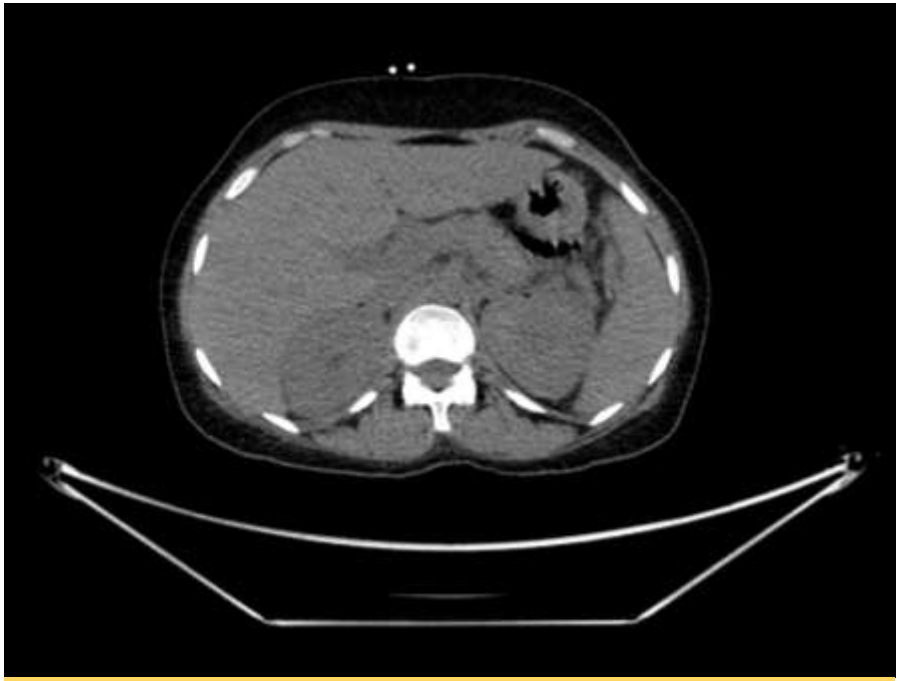
- Image Quality has received no complaints. Image noise measured in torso is lower than previous protocol.
- Possibility of reduction of mean effective head and neck CT dose from 1mSv to 0.6mSv.
- Other sites already have lower doses than us without ASiR. What image quality is deemed sufficient for localisation scans? Potential to go lower?
- All PET-CT scanner manufacturers have iterative reconstruction capabilities. Therefore further dose reduction in CT in PET envisaged in future.
- National dose audit would be extremely useful so as to know where we rank and what to aim for.

Full dose vs Reduced dose images?

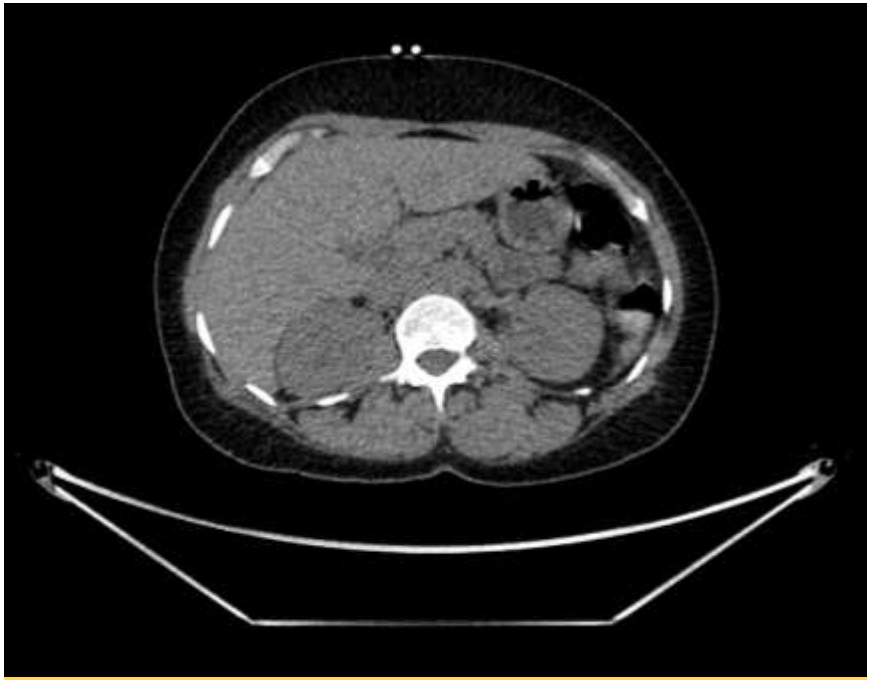
21% Dose Reduction

Old Protocol

Full dose vs Reduced dose images?



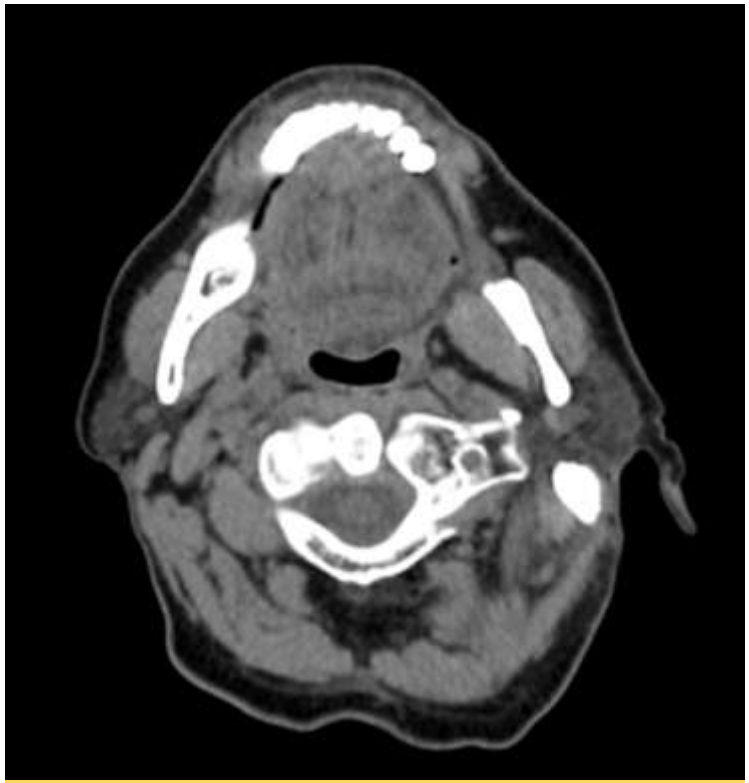
Old Protocol



48% Dose Reduction

Full dose vs Reduced dose images?

40% Dose Reduction



Old Protocol