Estimating Iodine Concentration from CT Number Enhancement

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Summary

- Background to the project
- Phantom measurements:
  - How is CT number related to iodine concentration?
  - Anthropomorphic phantom measurements
- Conclusions

Background - SPUtNIk

- SPUtNIk project: Accuracy and Cost-Effectiveness of Dynamic Contrast Enhanced Computed Tomography in the Characterisation of Solitary Pulmonary Nodules

Single **Pu**lmonary **N**odule **I**nvestigation

Background - SPUtNIk

- SPUtNIk project: Accuracy and Cost-Effectiveness of Dynamic Contrast Enhanced Computed Tomography in the Characterisation of Solitary Pulmonary Nodules
  - Single pulmonary nodules - ?malignant
  - Dynamic contrast enhanced CT to assess vascularity
  - Imaging pre-contrast and every 60s for 4 min
  - ROI drawn (manually) over nodule at widest part in each series
  - CT number plotted as a function of time
  - ‘Maximum’ enhancement over baseline
  - Previous work: > 15HU (at 120 kV) positive for malignancy

  Swensen et al, ‘Lung nodule enhancement at CT: multicentre study’, Radiology 2000; 214:73-80

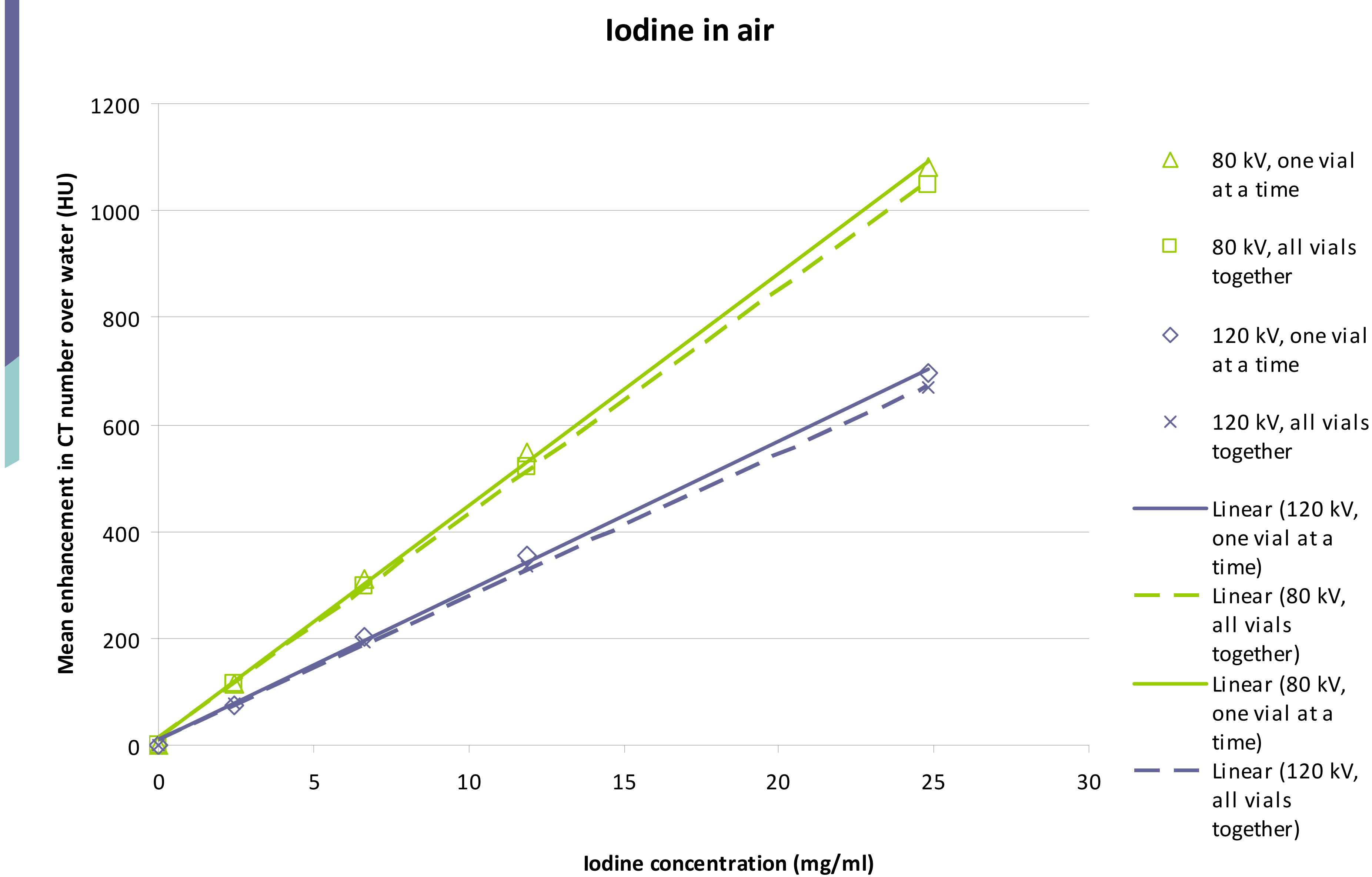
SPUtNIk – our concerns

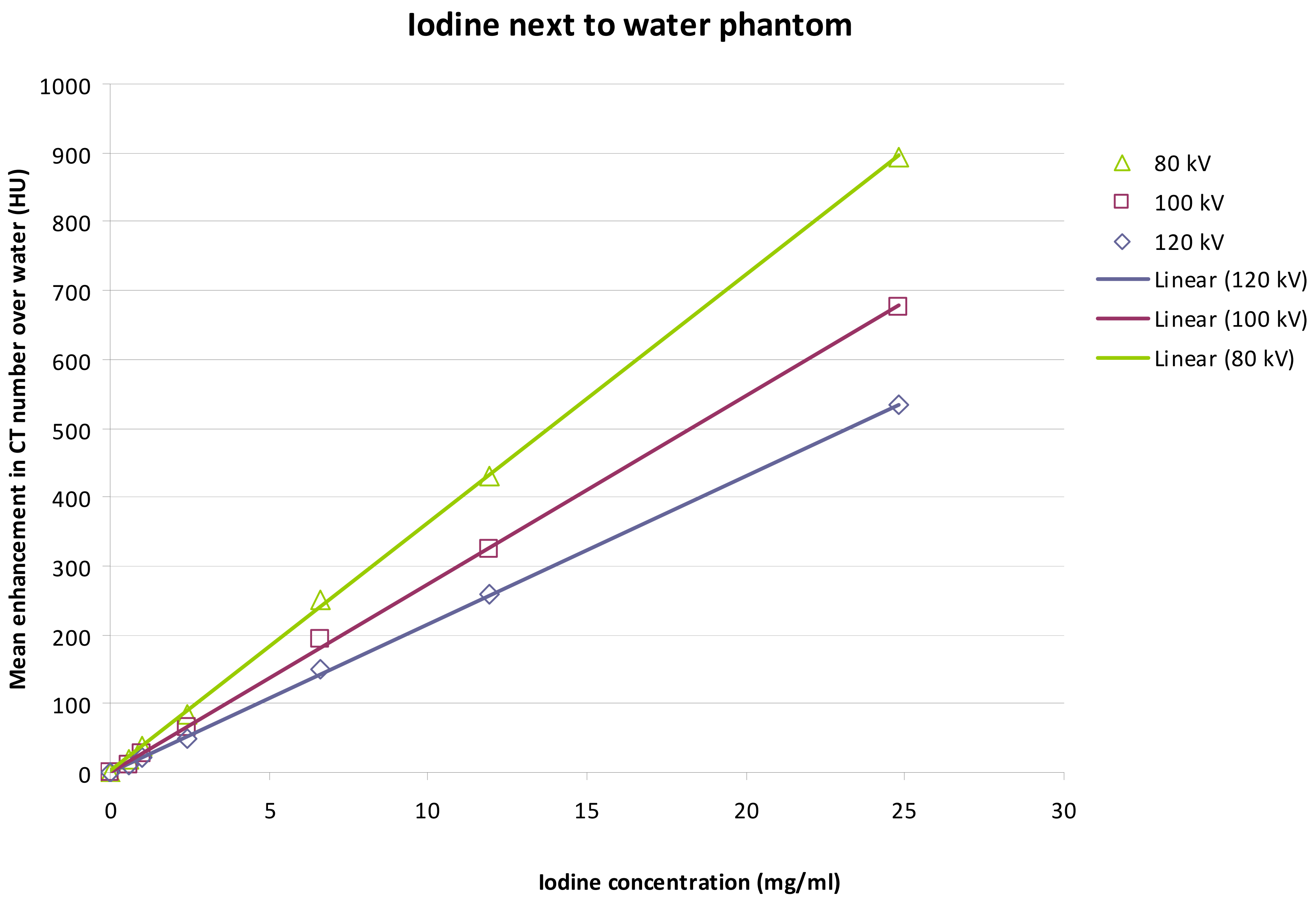
- Can we use a lower kV to increase enhancement and improve ENR (enhancement to noise ratio)?
  - Kalender et al (Med Phys 2009; 36:993-1007) show that CNRD is optimised at <60 kV for thorax imaging using iodine contrast, at a range of patient sizes
- Can we achieve adequate noise statistics at low kV, given the technical limitations on mAs?
- Does the size of the patient affect measured CT number?
- Does the location of the ROI (eg in lung, next to a rib, near the heart) affect CT number?

How is CT number related to iodine concentration?

CT number vs [I]

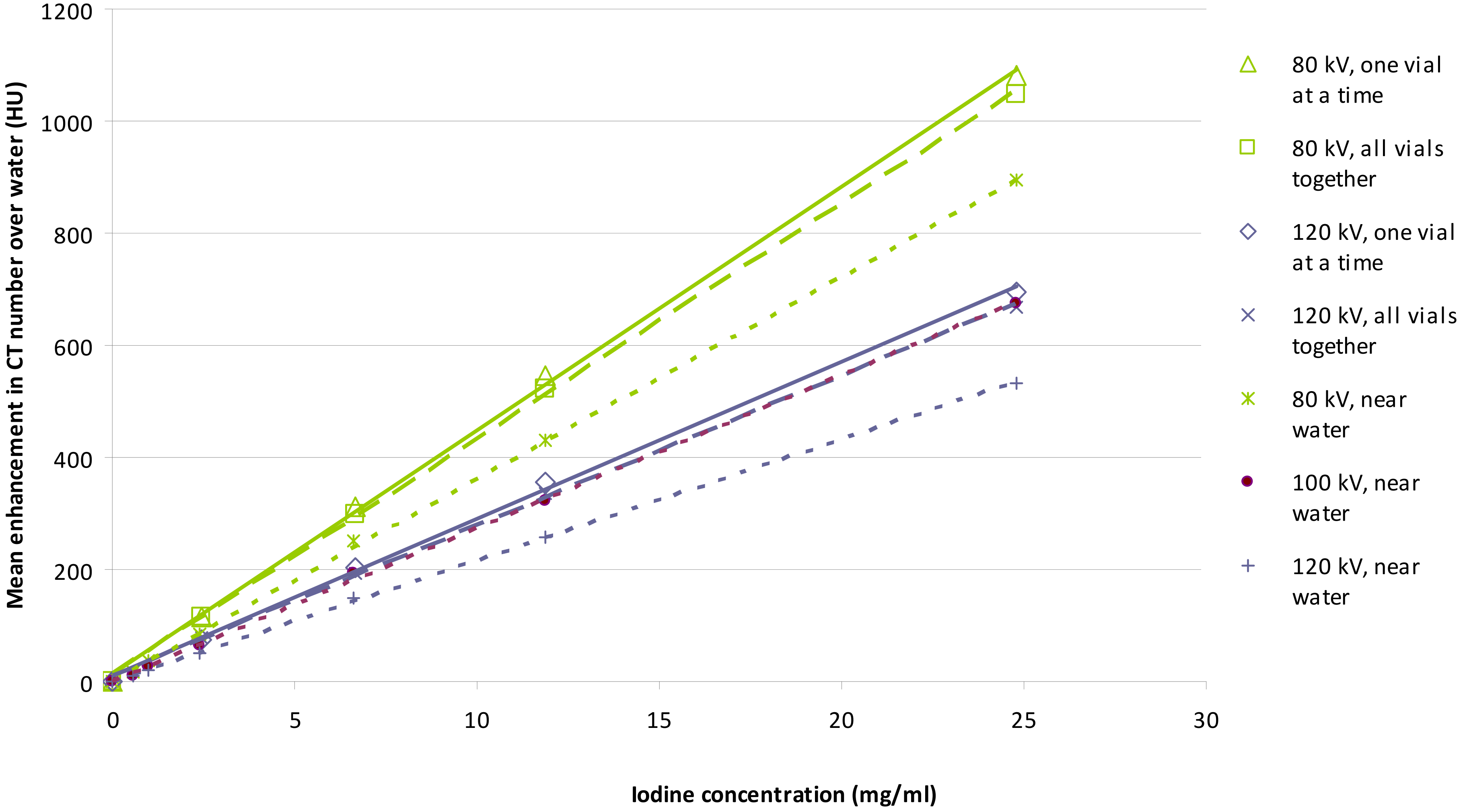
- Iodine
  - Optiray 350 contrast agent mixed with water
  - Concentration determined by measuring mass
  - Six iodine concentrations (0.57 – 24.8 mg/ml) and water
  - Expected concentration: 9 mg/ml in blood stream after complete mixing; threshold 0.6 mg/ml in nodule
- Scanner
  - Siemens Somatom Definition
  - 80, 100, 120 kV
  - CT number of vials in air and surrounding Siemens QA phantom
  - Vials scanned individually and adjacent to high iodine concentrations


Iodine in air
Mean enhancement in CT number over water (HU)
0
200
400
600
800
1000
1200
0
5
10
15
20
25
30
Iodine concentration (mg/ml)
80 kV, one vial at a time
80 kV, all vials together
120 kV, one vial at a time
120 kV, all vials together
Linear (120 kV, one vial at a time)
Linear (80 kV, all vials together)
Linear (80 kV, one vial at a time)
Linear (120 kV, all vials together)


Iodine next to water phantom
Mean enhancement in CT number over water (HU)
1000
900
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
Iodine concentration (mg/ml)
80 kV
100 kV
120 kV
Linear (120 kV)
Linear (100 kV)
Linear (80 kV)

CT number vs [I]

- Gradient of CT number vs iodine concentration changes depending on what else is in the field of view
- Beam hardening effects
  - More attenuation in the useful beam -> higher mean energy -> more penetrating -> material is less attenuating -> CT number is lower



Mean enhancement in CT number over water (HU)
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30
Iodine concentration (mg/ml)
80 kV, one vial at a time
80 kV, all vials together
120 kV, one vial at a time
120 kV, all vials together
80 kV, near water
100 kV, near water
120 kV, near water

CT number vs [I]

- Our results compared to previous measurements
- Miles (2007) found a significant variation between scanners AND over time
  - Attributed to anode pitting and changes in effective filtration over time

		CT no. to iodine ratio / HU (mg/ml)$^{-1}$		
kV	**Medium**	**This work**	**Miles (2007)**	**Miles (2001)**
80	air	42.0	38.8	
80	water	36.0	33.1	
100	air		30.5	
100	water	27.3	25.5	
120	air	26.8	25.6	26.5
120	chest			23.6
120	water	21.5	21.3	22.7
140	air		22.2	
140	water		17.4	

- Miles, Young, Chica & Esser, 'Quantitative contrast-enhanced computed tomography: is there a need for system calibration?', Eur Radiol 2007; 17:919-926
- Miles, Griffiths & Fuentes, 'Standardised perfusion value: universal CT contrast enhancement scale that correlates with FDG PET in lung nodules', Radiology 2001; 220:548-553

CT number vs [I]

- Our results compared to previous measurements
- Miles (2007) found a significant variation between scanners AND over time
  - Attributed to anode pitting and changes in effective filtration over time
- We will measure each scanner individually
  - Lung-equivalent phantom with I inserts
  - Radiographers will be provided with a water phantom with I inserts for consistency measurements over the timescale of the trial
  - New tubes?

		CT no. to iodine ratio / HU $(mg/ml)^{-1}$		
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80	air	42.0	38.8	
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120	water	21.5	21.3	22.7
140	air		22.2	
140	water		17.4	

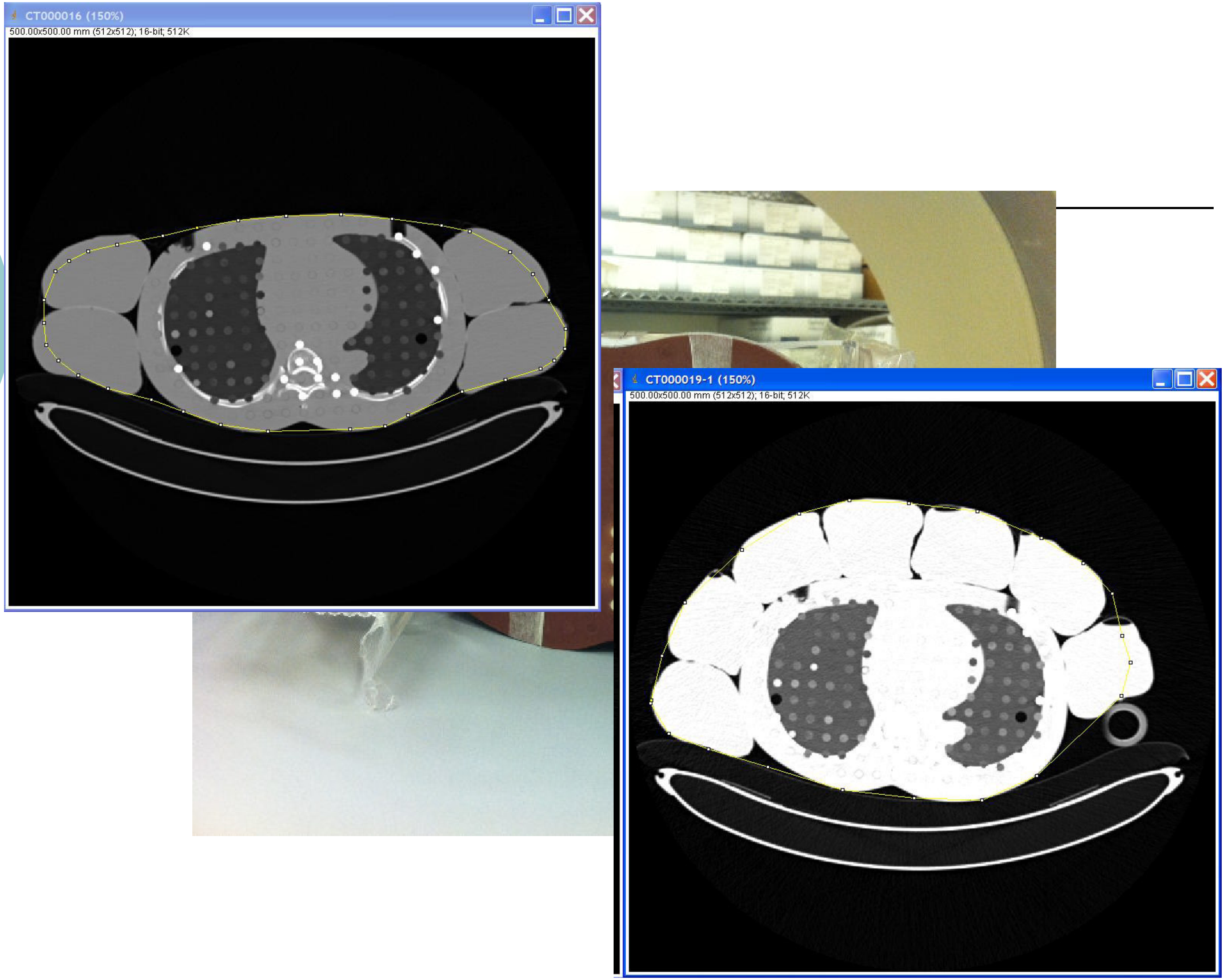
Anthropomorphic phantom measurements

Phantom measurements

- Does the CT number depend on where in the lung the iodine is located?
- Does it depend on the size of the patient?
- Do these effects change with kV?

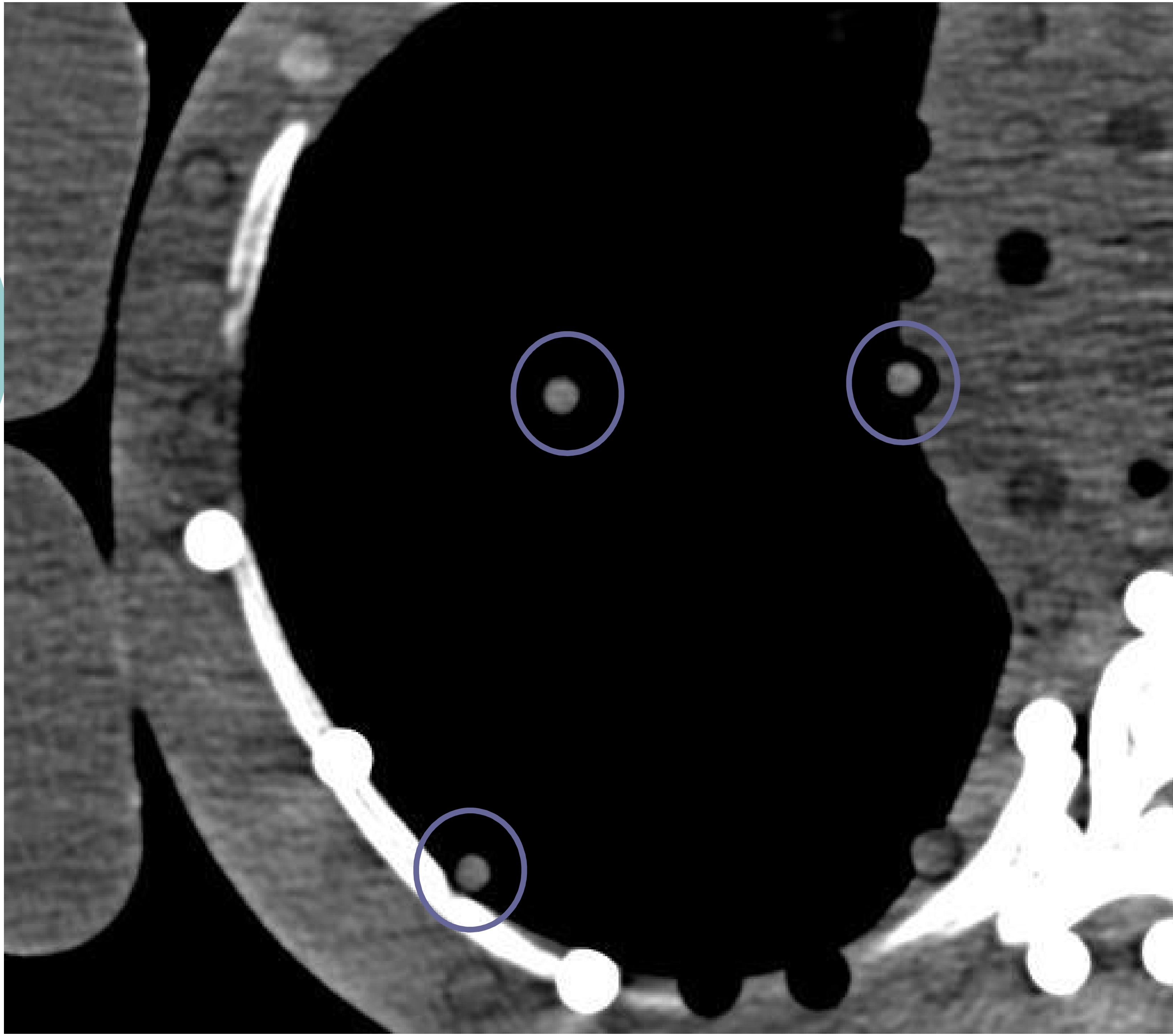
Method

- ART anthropomorphic phantom
  - Thorax section
  - ‘Plugs’ removed in 3 locations: central lung; near rib; near heart
- 1 ml syringe filled with iodine solution and inserted into channels
  - Two iodine solutions and water considered: 1.0 mg/ml, 0.6 mg/ml, 0.0 mg/ml
- Scanned at 80 kV, 100 kV, 120 kV
  - Reduced FOV (15 cm) used in accordance with trial protocol
- Three different patient ‘sizes’: 50 kg, 80 kg, 95 kg


CT000016 (150%)
500.00x500.00 mm (512x512); 16-bit; 512K
CT000019-1 (150%)
500.00x500.00 mm (512x512); 16-bit; 512K

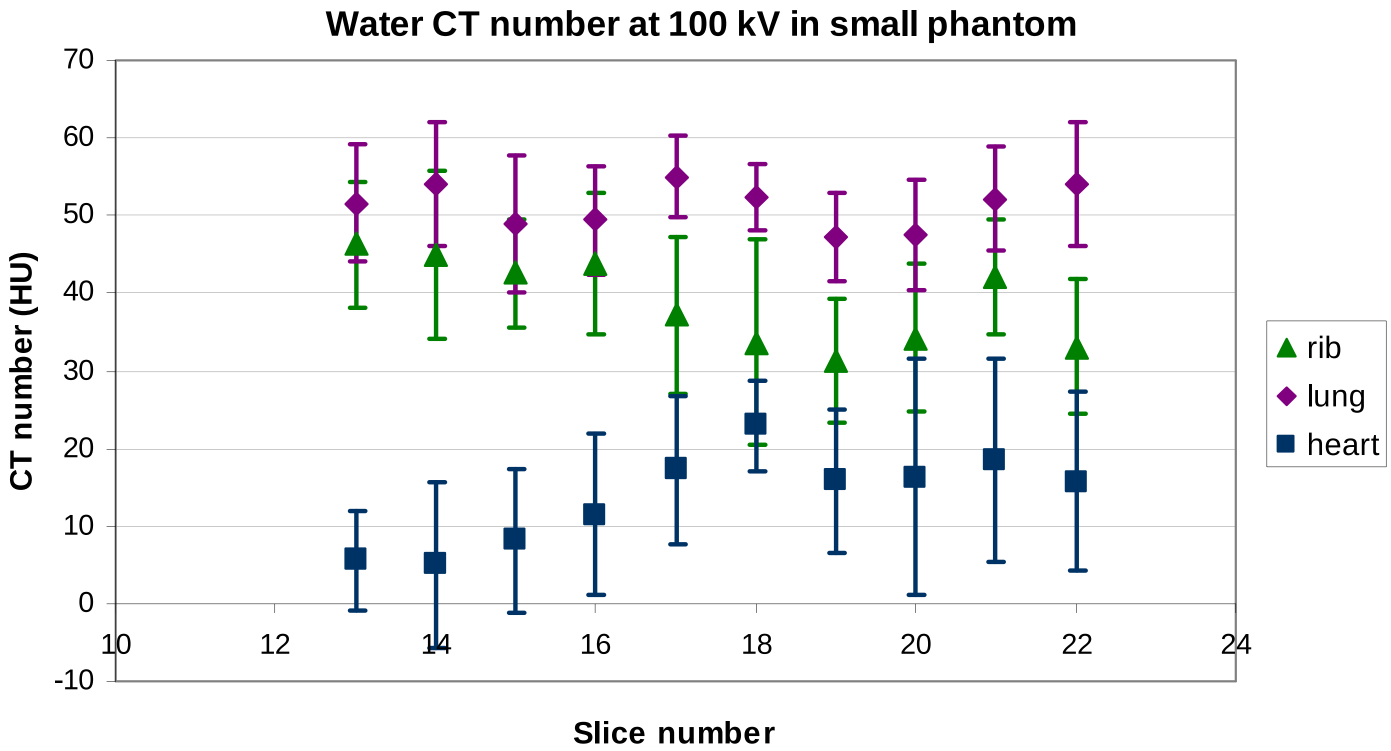
Method

- Images exported to CD and read with ImageJ
- ROI placed over central part of iodine solution
- ROI had to be moved manually as the phantom was not entirely straight and the ROI was small
- Inter-slice variation – measurements made at ≥7 slices, ignoring gaps between phantom slabs
- Mean and SD in CT number recorded for each ROI – nearly 2000 measurements in total



Method

- Considered CT number enhancement,
  ie CT#(iodine) – CT#(water) in same location.
  - The CT number of water varied significantly depending on location in the phantom, phantom size and kV

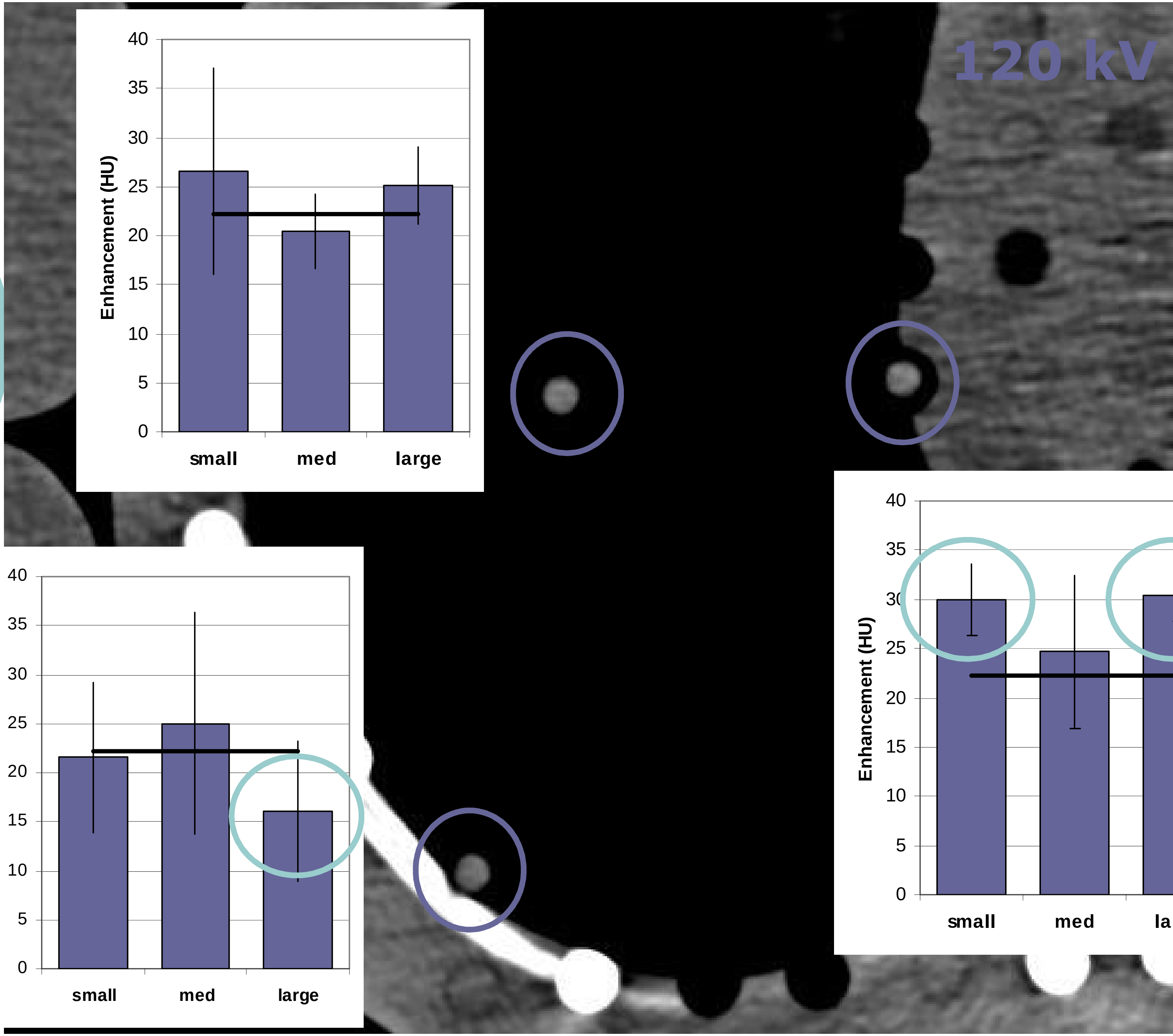


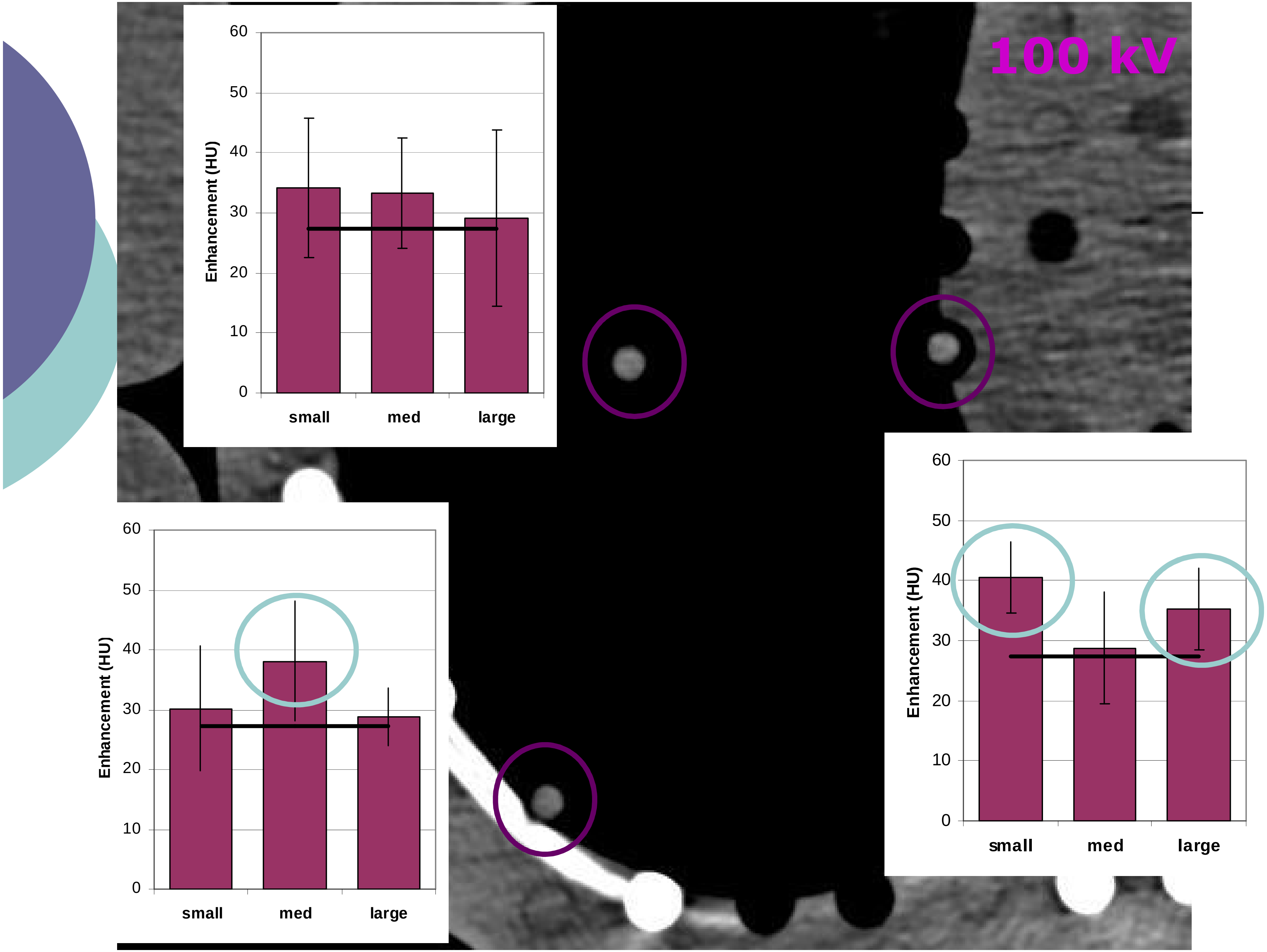
Method

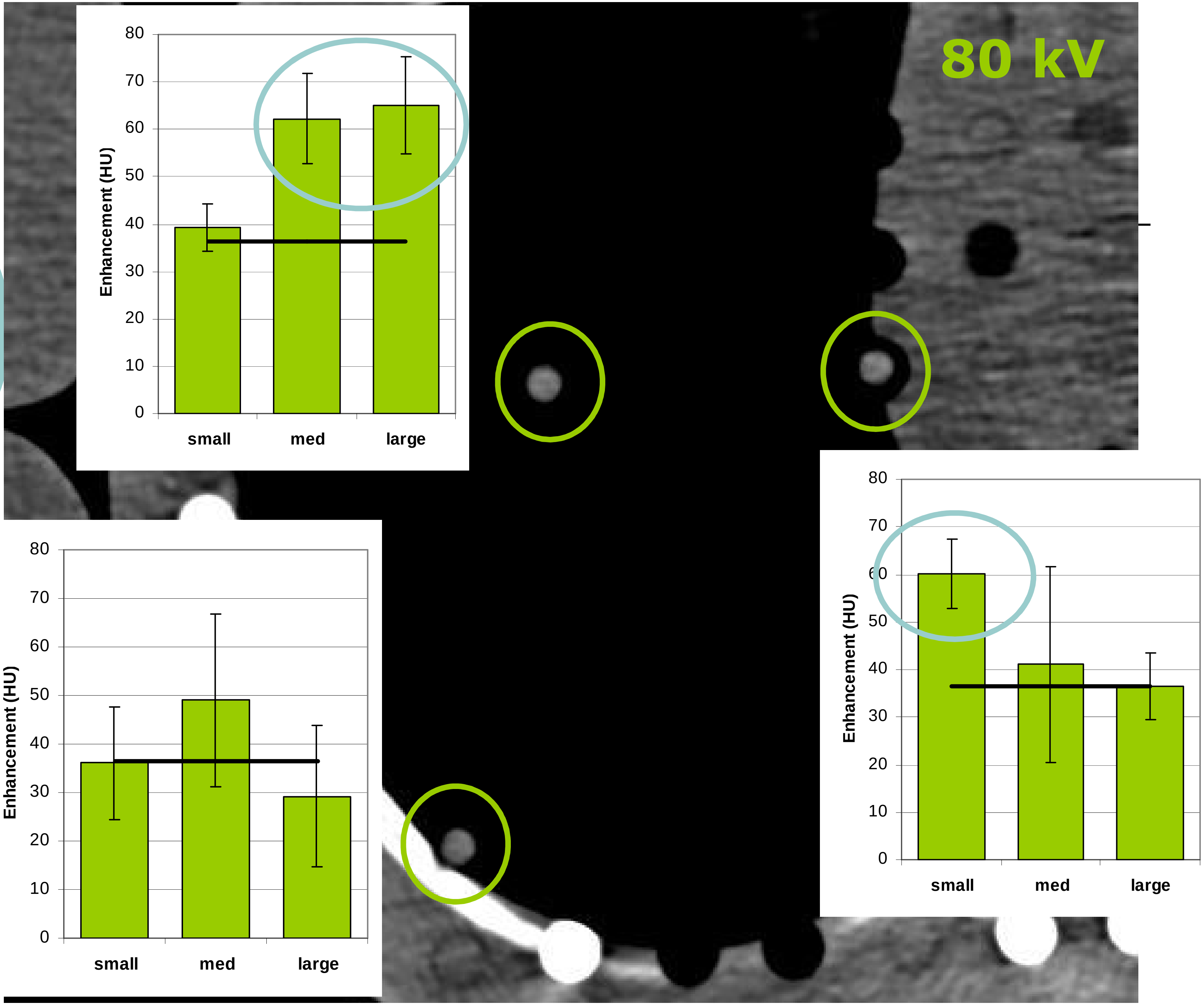
- Considered CT number enhancement, ie CT#(iodine) – CT#(water) in same location.
  - The CT number of water varied significantly depending on location in the phantom, phantom size and kV
  - Measuring enhancement more closely mimics the clinical situation where we are interested in increase in CT number compared to pre-contrast scan
- Excluded:
  - slices between slabs of phantom
  - air bubbles at ends of syringes
  - slices at base of lung where diaphragm begins to appear
- Take mean of CT number enhancement in all remaining slices
- Students T-test (2-talied) to assess significance of differences in enhancement between different locations in phantom and different patient sizes ($p<0.05$)

Results

- CT number varied with all parameters:
  - kV
  - Iodine concentration
    - Following results are for 1.0 mg/ml
  - Location within phantom
  - Phantom size


120 kV
Enhancement (HU)
40
35
30
25
20
15
10
5
0
small
med
large
Enhancement (HU)
40
35
30
25
20
15
10
5
0
small
med
large
Enhancement (HU)
40
35
30
25
20
15
10
5
0
small
med
large

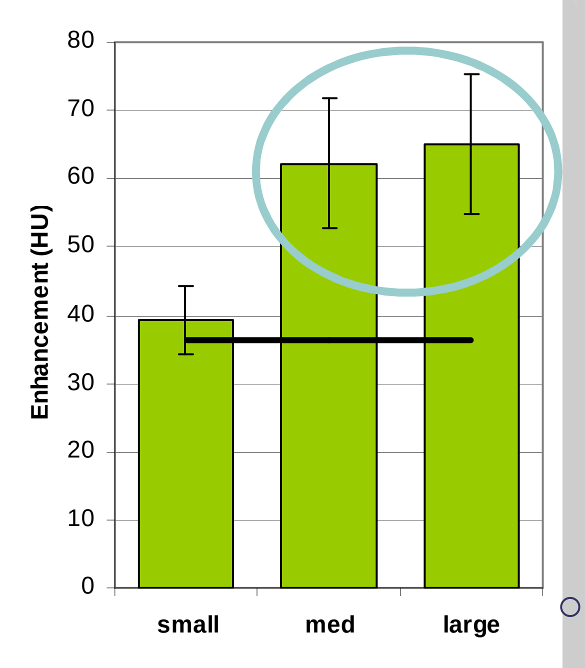

100 kV
60
50
40
30
20
10
0
Enhancement (HU)
small
med
large


80 kV
Enhancement (HU)
80
70
60
50
40
30
20
10
0
small
med
large

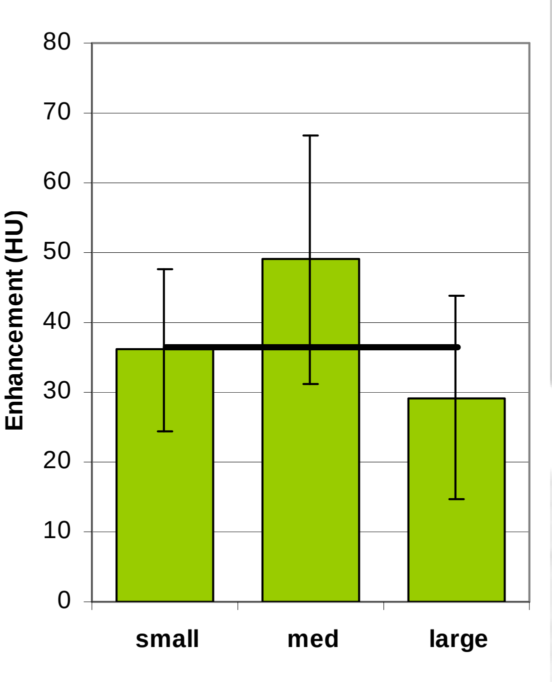
Analysis

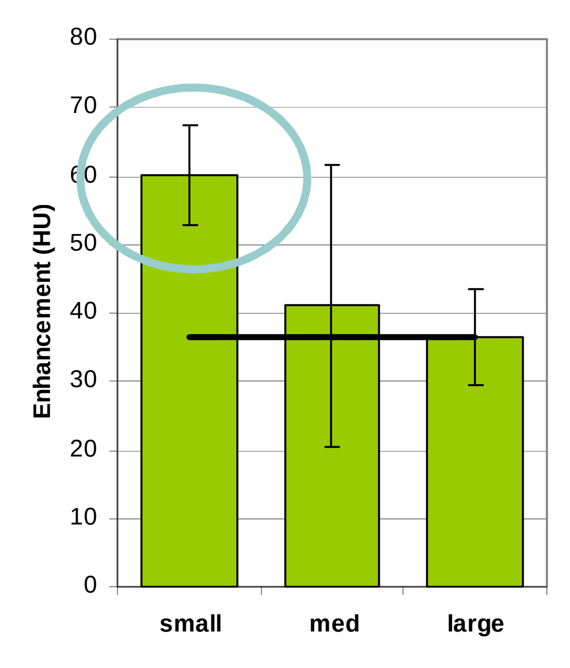
- Enhancement is a bit erratic
- Generally:
  - Enhancement slightly depressed near ribs – beam hardening artefacts
  - Enhancement near heart is variable – beam hardening effects vs beam hardening correction?
  - Enhancement in lung tissue near expected, except at 80 kV (high)
- Remember, considering enhancement not simply CT#
- Which kV should we use for the trial?

80 kV

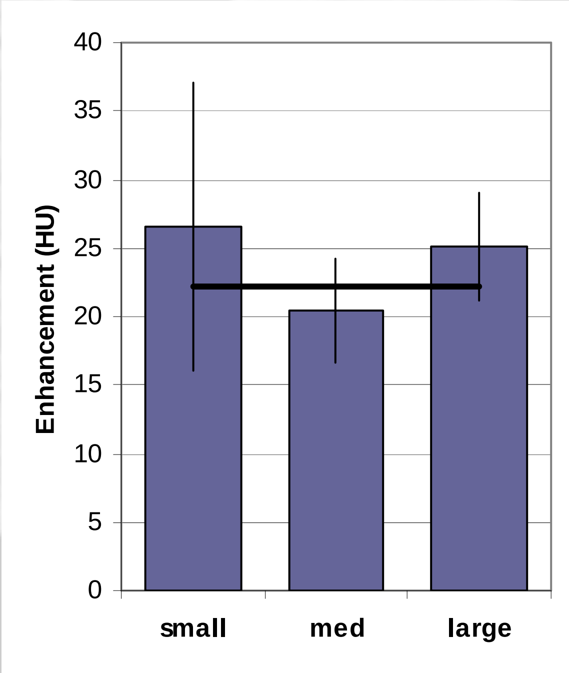


- Decided not to use 80 kV
  - Statistically significant variation in enhancement, depending on location within phantom and phantom size
- At 80 kV there is a significant difference in beam quality at different positions in the phantom
  - Difficulties in obtaining high enough mAs to keep noise low and ENR high for large patients

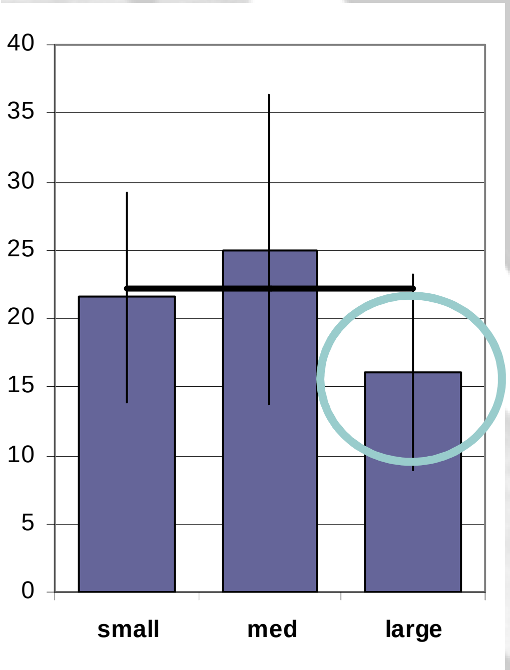




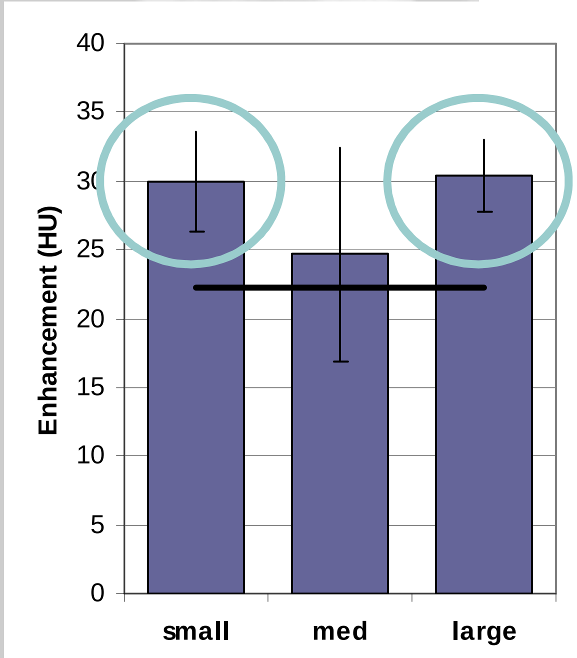
120 kV



- Decided against 120 kV too:
  - Enhancement in the large phantom varied significantly between positions

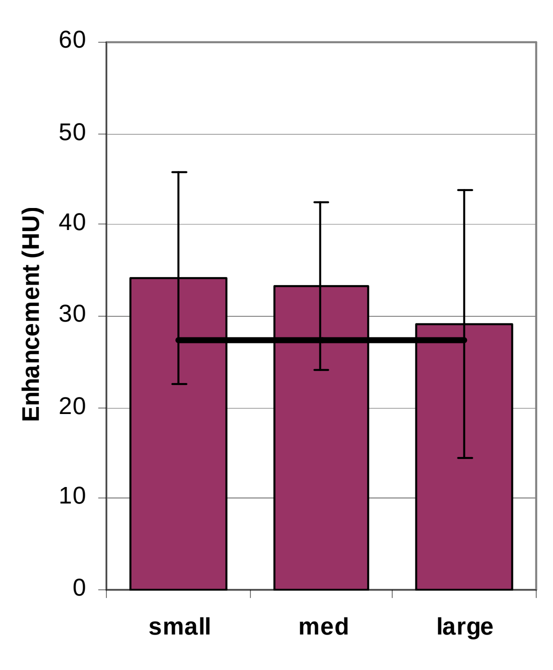


- Since enhancement values are lowest, a high dose needs to be delivered to obtain reasonable ENR (> 1.5 ?)*

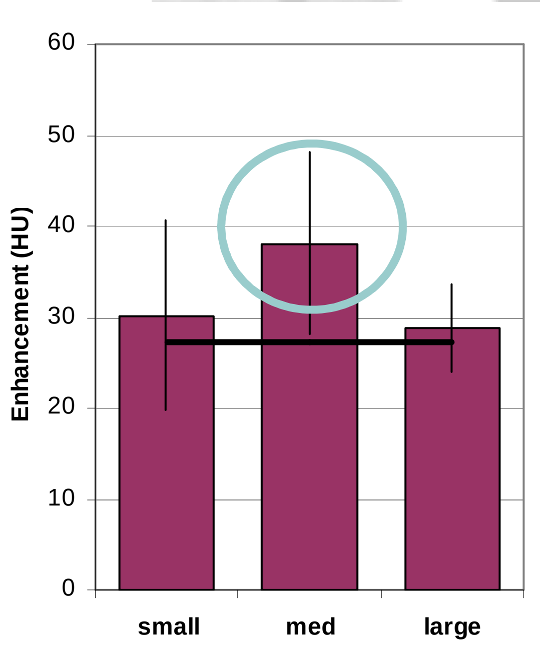


*Miles et al 'Current status and guidelines for the assessment of tumour vascular support with dynamic contrast-enhanced computed tomography' (Eur Radiol. 2012; 22:1430-1441), suggests ENR > 1.5.

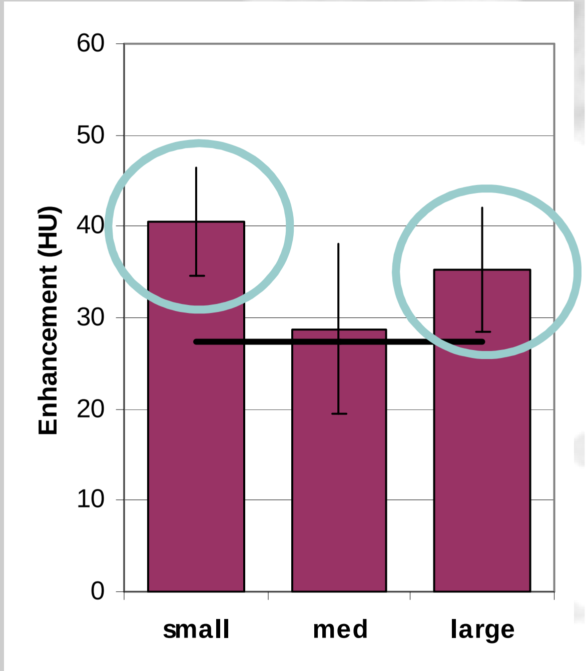
100 kV



- We will use 100 kV in the SPUtNIk trial
  - Least variation between phantoms and positions
  - ENR > 1.5 at reasonable CTDI
  - Threshold enhancement of 20 HU



Mass (kg)	mAs	ENR	CTDI (mGy)
< 60	200	2.1	8.6
60 – 90	350	1.6	15.1
> 90	500	1.7	21.6



Analysis

- Limitations:
  - Hard to know what patient mass our phantoms are
  - ROI very small for 1ml syringes (area 5.9mm^2 / diameter 2.7mm). *Nodules in trial will be >8mm, ROI drawn on widest axial slice at 70% nodule diameter on lung window*
  - Uncertainty in [I] and/or non-uniform distribution along syringe. *Minimised by shaking our 'stock' vial before drawing into the syringe*
  - Position of 'heart' ROI – in the heart itself for some slices, in the lung for others
  - Since reduced FOV used, not sure what beam hardening correction is being applied. *We will use a patient-size phantom with reduced FOV for the scanner assessments*

Conclusions

Conclusions

- CT number does increase with increasing iodine concentration, but…
  - Need to use enhancement over baseline, rather than raw CT number
  - Be aware of the limitations and uncertainty in enhancement measurements
  - Think about what phantom to use to check the CT# / [I] for your scanner. Air? Water? Lung?
  - The kV you choose will depend on the application and required ENR
  - All of these things will vary between scanners and recon kernels

Acknowledgements

- Maria Lewis (Guy's & St Thomas')
- SPUtNIk trial group

SPUtNIk

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HTA

Project ref. 09/22/117

Southampton NHS
University Hospitals NHS Trust

SPUtNIk

Single **Pu**lmonary **N**odule **I**nvestigation

- Sites taking part in the trial:
  - Aberdeen
  - Brighton & Sussex
  - Glasgow
  - Mount Vernon
  - Oxford
  - Papworth
  - Southampton
  - UCH London

Thank you for listening

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