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
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

**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 bloodstream 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)

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

- Iodine concentration (mg/ml)
- Mean enhancement in CT number over water (HU)

- 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 $\rightarrow$ higher mean energy $\rightarrow$ more penetrating $\rightarrow$ material is less attenuating $\rightarrow$ CT number is lower
Iodine concentration (mg/ml)

Mean enhancement in CT number over water (HU)

- 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

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- 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?

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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
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, i.e., $\text{CT#(iodine)} - \text{CT#(water)}$ in same location.
  - The CT number of water varied significantly depending on location in the phantom, phantom size and kV.

Water CT number at 100 kV in small phantom
Method

- Considered CT number enhancement, i.e., $CT_\text{water} - CT_\text{iodine}$ in the 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-tailed) 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
Results – 80 kV

100 kV

Enhancement (HU)

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

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
Analysis

Limitations:

- Hard to know what patient mass our phantoms are
- ROI very small for 1ml syringes (area 5.9mm² / 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

Project ref. 09/22/117
SPUtNIk

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

Single Pulmonary Nodule Investigation
Thank you for listening

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