CT Optimisation for Paediatric SPECT/CT Examinations

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Outline

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Introduction

- New SPECT/CT installed at BCH
  – Siemens Symbia T6
  – I was STP trainee at QEHB at start of project
- Consultant radiologist wanted to utilise diagnostic quality 6 slice CT
- One stop shop to speed up diagnosis, reduce patient discomfort, and reduce number of return visits
- Need to set up CT protocols from scratch

Challenge

- When compared to other imaging modalities (i.e. MR and CT) the use of SPECT/CT within paediatrics is comparatively low which is partly due to lack of:
  - formal guidelines and training
  - published data or evidence to support paediatric hybrid imaging
- Also, clinicians are reluctant to refer children for SPECT/CT because of:
  - an increased risk of developing future radiation related cancer [1]
  - an unnecessarily high dose of radiation if CT settings not adjusted for their smaller body size
- Need to optimise SPECT/CT for paediatric studies to reduce the risk to the patient
- If underutilised, may result in undiagnosed illness or disease.

Aims and Objectives

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- Perform optimisation for CT acquisitions for SPECT/CT studies in a paediatric hospital
- Define CT imaging requirements with radiologists for an initial SPECT/CT investigation
- Determine optimal CT imaging parameters for initial paediatric study by:
  - Deciding on a reasonable range of acquisition parameters
  - Reducing the number of feasible protocols through quantitative assessment
  - Define image criteria for radiologists to qualitatively score image quality
  - Define optimal protocol with consideration of radiologist image scoring, calculated effective dose and quantitative image quality measurements
- Define departmental $CTDI_{vol}$ and DLP reference values for a range of patient weights

Methods:
1. Requirements

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- Discussed with radiologist which exam should be priority
- The initial optimisation project selected was mIBG SPECT/CT
  - Iodine -123 mIBG is used to find or confirm the presence of neuroendocrine tumours [3]
  - Diagnostic quality CT (which is unusual for mIBG studies) and Attenuation Correction (AC) CT required
  - Region of interest is generally thorax to pelvis.
  - Already criteria for SPECT images [4]
    - ➢Need criteria for CT images

Methods:
2. Equipment

- SPECT/CT camera:
  - Siemens Symbia T6
- Phantoms:
  - Child and adult anthropomorphic Kyoto phantoms
  - Child phantom based on the weight and height of a 5 year old (20 kg and 105 cm)
  - Adult phantom based on the weight and height of an average Asian adult (50 kg and 165 cm) which is equivalent to a UK 15 year old
  - Catphan 424 image quality phantom

Methods:
3. Setting up parameters

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The parameters recommended for paediatric and adult abdomen routines in the Siemens applications guide are:

Paediatric		Adult	
kV	110	kV	110
Reference mAs	50	Reference mAs	100
AEC	CARE Dose4D	AEC	CARE Dose4D
Pitch	1.5	Pitch	1.5
Slice width	5 mm	Slice width	5 mm
Collimation	6 x 2 mm	Collimation	6 x 2 mm
Reconstruction kernel	B41s	Reconstruction kernel	B41s

These were used as the reference settings

Methods:
3. Setting up parameters

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- Acquisition parameters were based on the manufacturers recommended settings [5]
  - varied systematically to produce a range of images of a “5 year old” (approx. 20 kg) and “15 year old” (approx. 50 kg)
- Parameters varied:
  - 3 different kVs (80, 110, and 130)
  - 7 different mAs (20, 25, 40, 50, 60, 80, and 100)
  - 5 different pitches (0.5, 0.75, 1.0, 1.5, and 2.0)
  - 4 different slice widths (2.5, 3, 4, and 5 mm)
  - 3 different collimations (1, 2, and 3 mm)
  - CARE Dose 4D on or off

Results:
1. Data sorting

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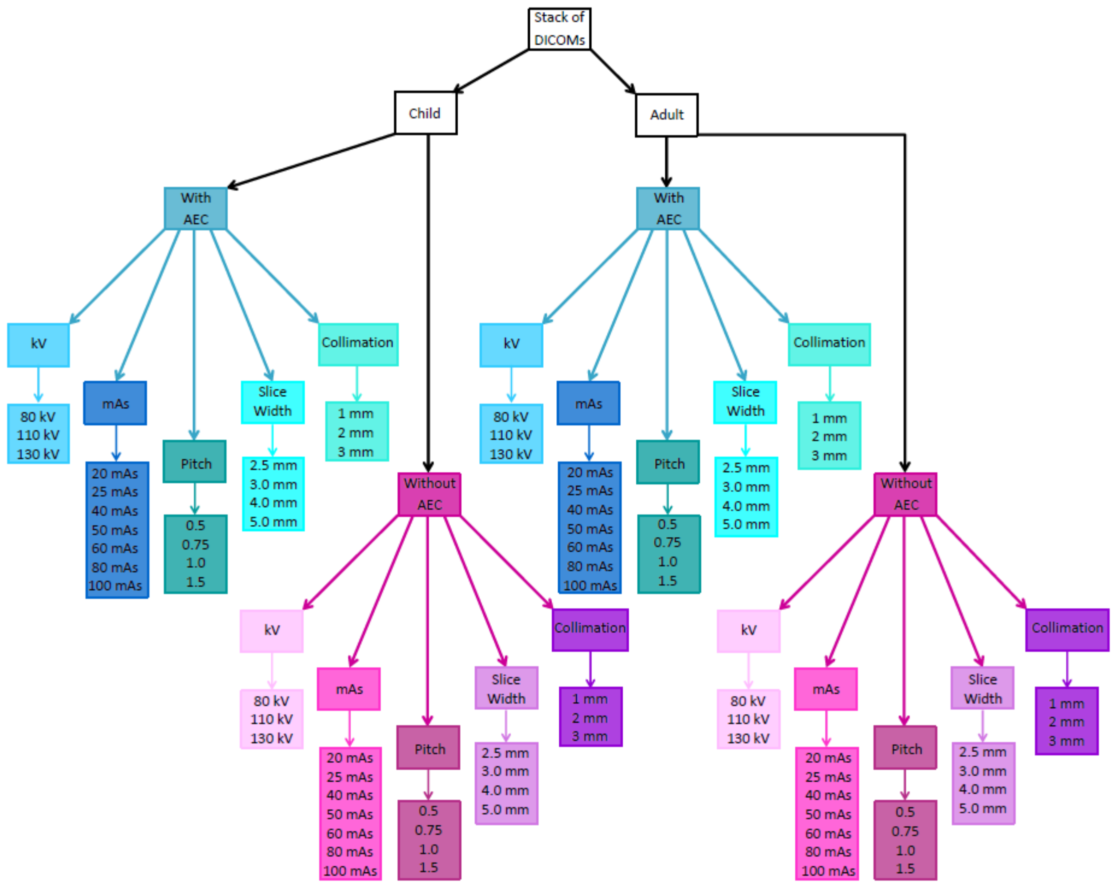
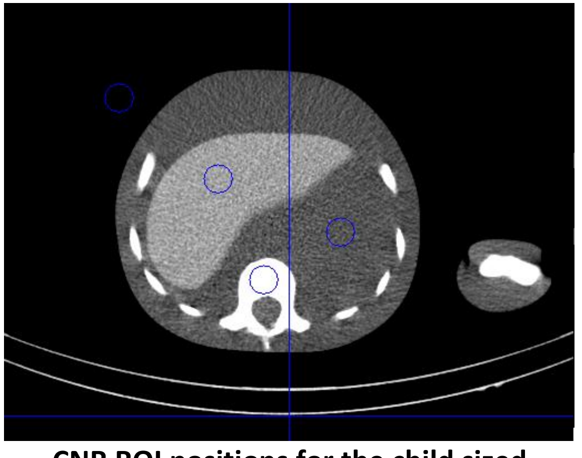
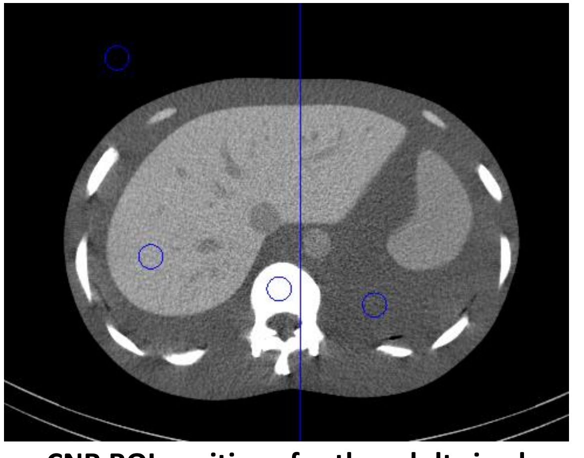


Results:
2. Data filtering - CNR

- The full ranges of image series' were filtered according to liver to soft tissue Contrast to Noise Ratio (CNR) and Size Specific Dose Estimate (SSDE)
- The manufacturers recommended acquisition parameters were used for the reference images



CNR ROI positions for the child sized phantom



CNR ROI positions for the adult sized phantom

$$CNR = \frac{|m_{liver} - m_{tissue}|}{\sqrt{\frac{\sigma_{liver}^2 + \sigma_{tissue}^2}{2}}}$$

Results:
2. Data filtering - CNR

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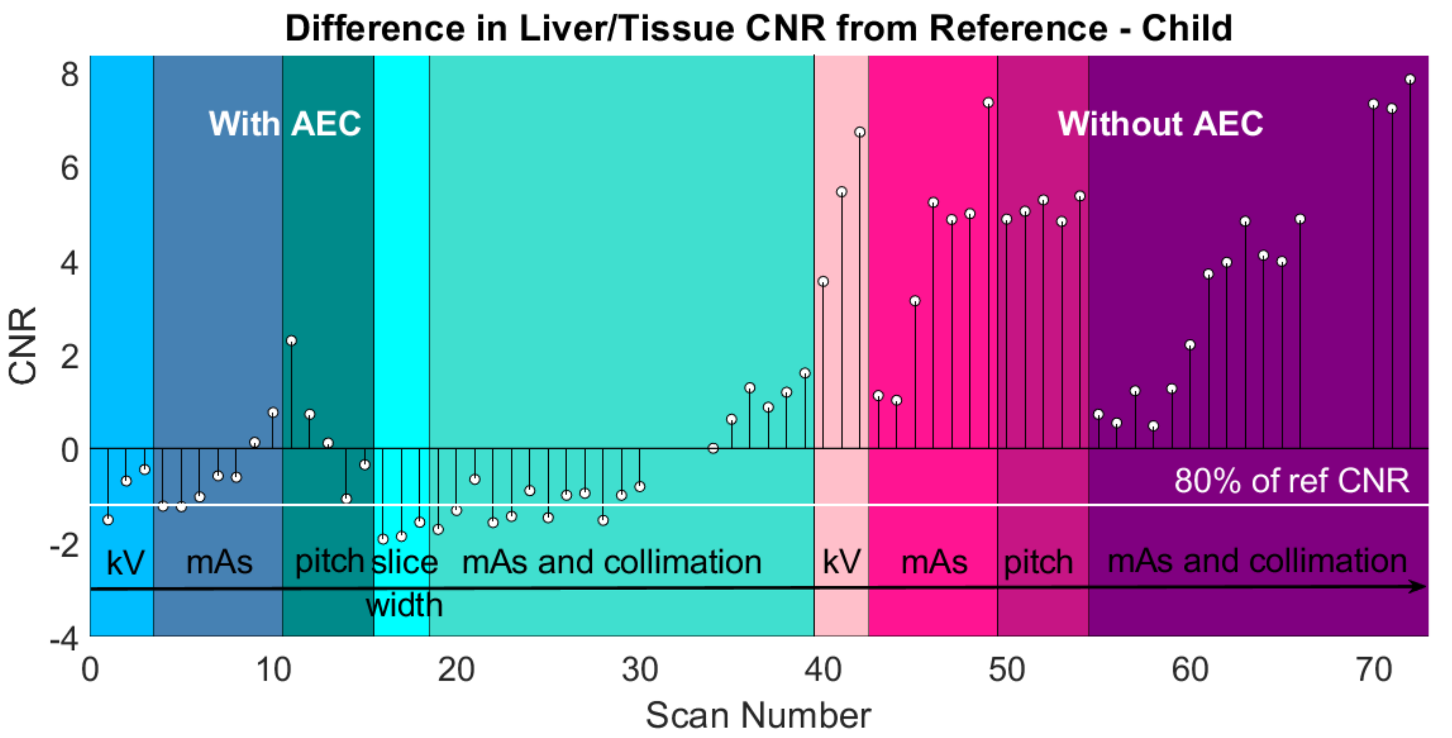
- The minimum required CNR was decided by a radiologist after a brief review of the images
  - The reference images (recommended manufacturers protocols) were presented alongside images with minimum CNR, -20%, -10%, +10%, and +20% of the reference CNR
  - The radiologist decided which CNR threshold was clearly unsuitable for an initial reduction of possible protocols
- Images with CNR <80% of the reference image would never be acceptable for diagnostic images

  → All images with CNR below this threshold were removed from consideration.

Results:
2. Data filtering - CNR



Results:
2. Data filtering - CNR

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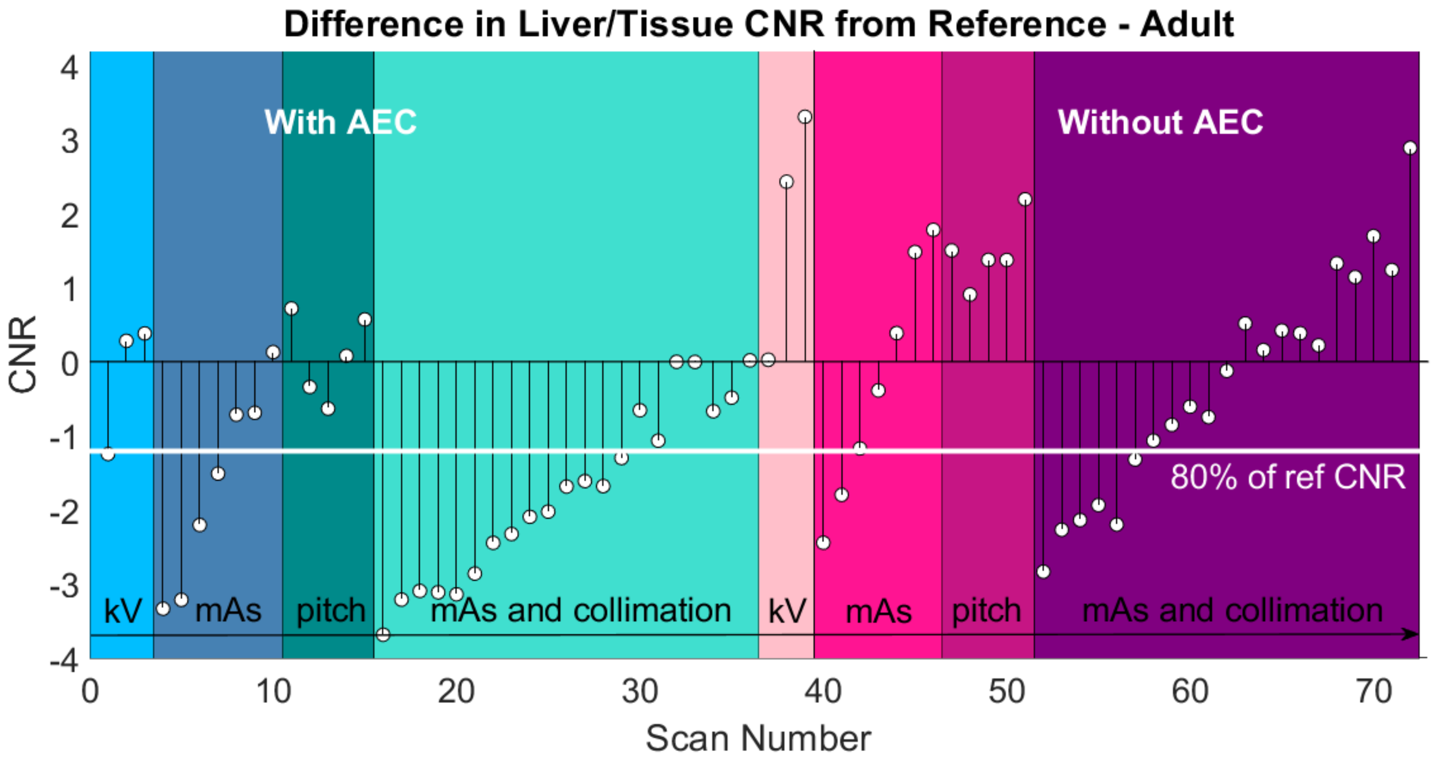

Results:
3. Data filtering – SSDE

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- The proposed NDRL for adult SPECT/CT mIBG is a DLP of 240 mGy.cm and $CTDI_{vol}$ of 5.4 mGy [6]
  - This $CTDI_{vol}$ was used to calculate an SSDE for the "average" size adult (eff. diameter 30 cm)
  - Provisional maximum SSDE threshold was set for the child and adult phantoms by using the Imaging Gently mAs Reduction Factors table for the Pediatric Body [7], [8]
- The Size Specific Dose thresholds for the child and adult phantoms were calculated to be 4 and 6 mGy respectively
- The SSDE is an estimation of dose at the centre of a CT scan range that can be used for easy reference and for monitoring

$$SSDE = CTDI_{vol} \times size\ specific\ conversion\ factor$$

Results:
3. Data filtering – SSDE

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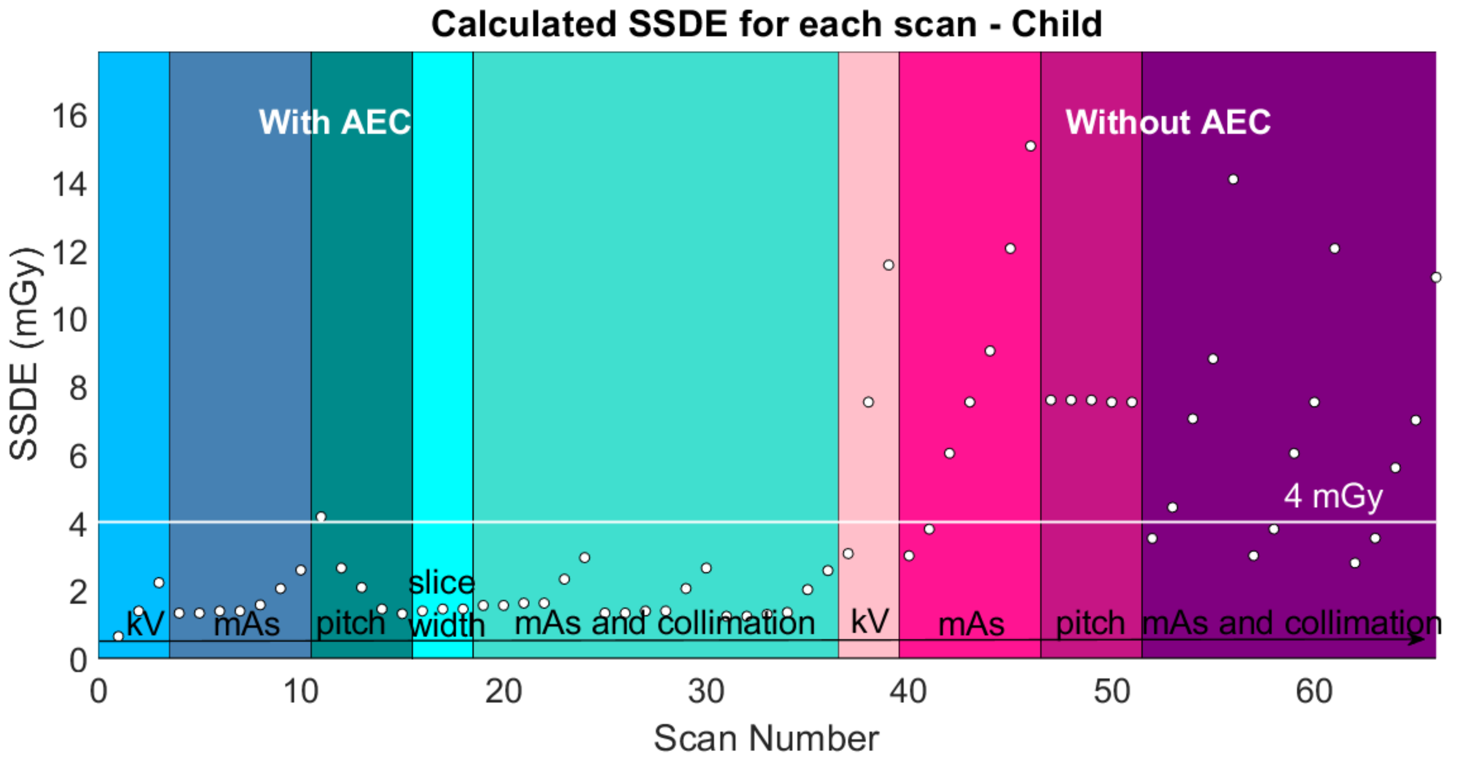

Results:
3. Data filtering – SSDE

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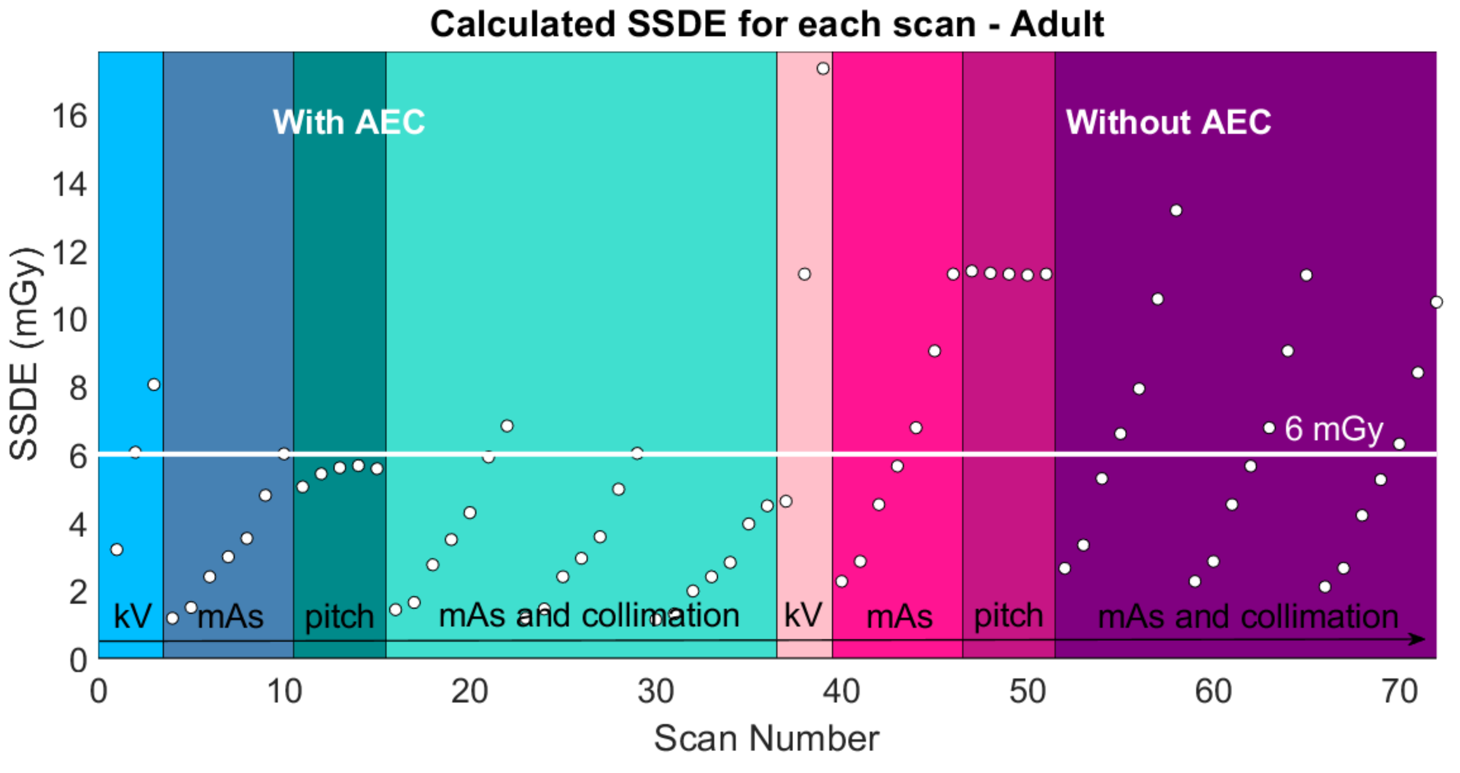

Results:
3. Data filtering – SSDE

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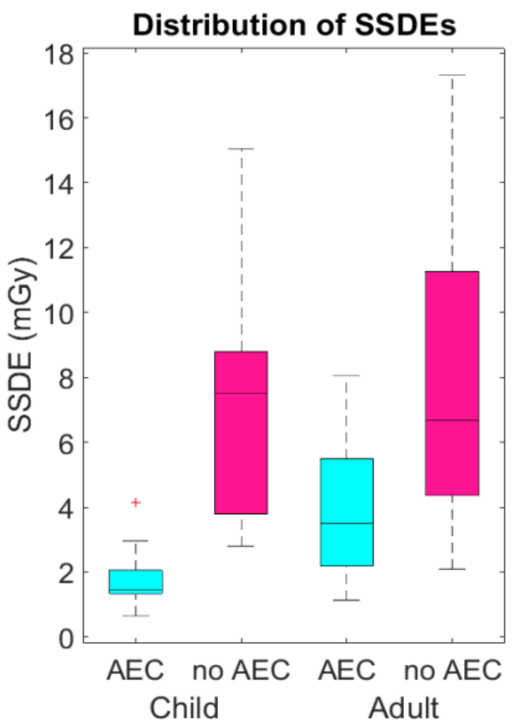
- Interquartile ranges show that the distributions of SSDEs for AEC are narrower than those without using the AEC
- With AEC the mAs is modulated to maintain consistent image quality for each image slice and each protocol
- Median values for no AEC are higher than with AEC
- Median SSDE for the child protocols with no AEC is higher than that of the adult protocols with no AEC
- Interquartile ranges for the adult and child protocols with no AEC are comparable
- Using the AEC to moderate the radiation exposure is simpler and more effective for varying patient sizes than not utilising the AEC



Boxplots showing the distribution of SSDEs for the child and adult sized phantoms, both with and without using the AEC

Results:
4. Data selection

- After applying CNR and SSDE thresholds
  - 35 possible child protocols
  - 32 possible adult protocols
- Needed a more manageable number for radiologist scoring
  - 9 child protocols
  - 8 adult protocols

Results:
4. Data selection

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CHILD Protocol No.	kVp	Ref mAs	Single Collimation (mm)	Pitch	Slice Width (mm)
1	110	50	2	1.5	5
2	80	50	2	1.5	5
3	110	25	2	1.5	5
4	110	50	2	0.75	5
5	110	50	2	1	5
6	110	50	2	1.5	2.5
7	110	40	1	1.5	5
8	110	40	2	1.5	5
9	110	40	3	1.5	5

ADULT Protocol No.	kVp	Ref mAs	Single Collimation (mm)	Pitch	Slice Width (mm)
1	110	100	2	1.5	5
2	80	100	2	1.5	5
3	110	50	2	1.5	5
4	110	100	2	0.75	5
5	110	100	2	1	5
6	110	50	1	1.5	5
7	110	50	3	1.5	5
8	110	100	3	1.5	5

Results:
5. VGC scoring

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- The selected images were transferred to PACS at two Trusts for radiologists to access and review under normal reporting conditions
- The images were to be judged absolutely against appropriate image quality criteria from the European Guidelines [9] using a 6-grade scale:
  1) Unacceptable
  2) Substandard
  3) Acceptable
  4) Above average
  5) Superior
  6) Not applicable
- The images were also to be judged for overall quality of the image series:
  1) Suitable diagnostic quality
  2) Borderline diagnostic quality
  3) Poor/unusable diagnostic quality [10]

1. Visually sharp reproduction of the liver parenchyma

Child

No.	1	2	3	4	5	6	7	8	9
Series Desc.	kV110	40mAs 1mm col	kV80	40mAs 2mm col	40mAs 3mm col	mAs25	Slice 2.5mm	Pitch 0.75	Pitch 1.0
Score									

2. Visually sharp reproduction of the kidneys

Child

No.	1	2	3	4	5	6	7	8	9
Series Desc.	kV110	40mAs 1mm col	kV80	40mAs 2mm col	40mAs 3mm col	mAs25	Slice 2.5mm	Pitch 0.75	Pitch 1.0
Score									

3. Visually sharp reproduction of the liver hilus

Child

No.	1	2	3	4	5	6	7	8	9
Series Desc.	kV110	40mAs 1mm col	kV80	40mAs 2mm col	40mAs 3mm col	mAs25	Slice 2.5mm	Pitch 0.75	Pitch 1.0
Score									

4. Visually sharp reproduction of the renal parenchyma

Child

No.	1	2	3	4	5	6	7	8	9
Series Desc.	kV110	40mAs 1mm col	kV80	40mAs 2mm col	40mAs 3mm col	mAs25	Slice 2.5mm	Pitch 0.75	Pitch 1.0
Score									

Results:
6. Calculating effective dose

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- The estimated effective dose was calculated using ImPACT CT Dosimetry software
- The child phantom is approximately representative of a 5 year old and the adult phantom is approximately representative of a 15 year old
- The estimated effective doses were used to add weighting to the analysis of the Visual Grading Characteristic scores

	Head and Neck	Chest	Abdo & Pelvis
Adult	1.0	1.0	1.0
15 y	1.1	1.0 - 1.1	1.0 - 1.1
10 y	1.2 - 1.3	1.1 - 1.4	1.2 - 1.5
5 y	1.6 - 1.7	1.2 - 1.6	1.2 - 1.6
1 y	2.2	1.3 - 1.9	1.3 - 2.0
Newborn (0 y)	2.3 - 2.6	1.4 - 2.2	1.4 - 2.4

Typical normalised effective doses to paediatric patients relative to adults

Results:
7. Measuring Image Quality

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- Catphan IQ phantom scanned using same parameters as images being scored
- IQ measurements:
  - Noise
  - Uniformity
  - Contrast spheres
  - Resolution
  - CT number

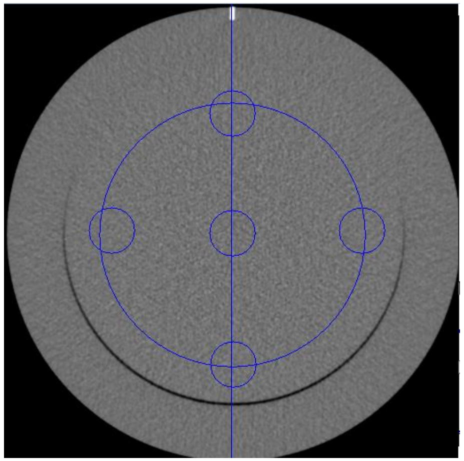

Figure 1: Uniformity slice with ROIs

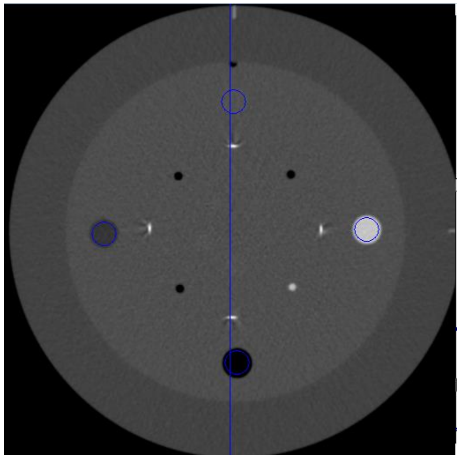

Figure 2: CT number slice with ROIs

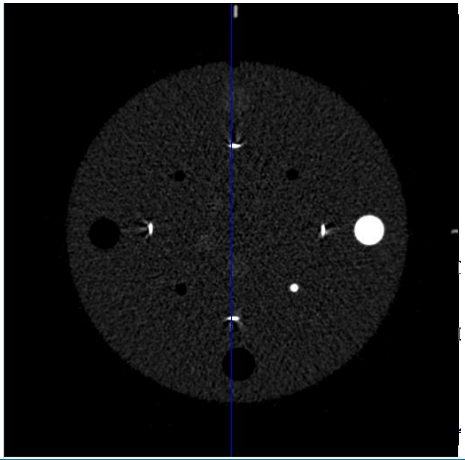

Figure 3: CT number slice windowed for contrast spheres

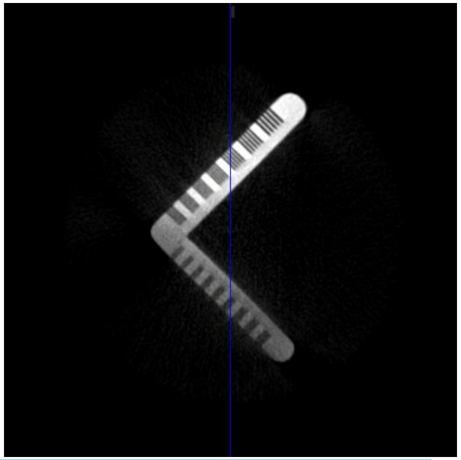

Figure 4: Spatial resolution slice

Results:
8. VGC Analysis

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- Image assessment scores were returned by one radiologist
- Protocols scored as (1) suitable diagnostic quality were considered to suitably fulfil their clinical purpose
- To obtain weighted scores:
  - Radiation dose weighted score: sum of scores for each protocol were divided by SSDE
  - IQ weighted score: IQ results were ranked and then averaged. The sum of scores was then divided by the mean IQ rank to determine the IQ weighted score
  - The final score for each protocol was the sum of the weighted scores

Results:
8. VGC Analysis

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- The final scores were then ranked, where the number one ranking protocol has the highest final score

CHILD	Protocol No.						
	1	**4**	**5**	**6**	**7**	**8**	**9**
Sum of scores	27.00	34.00	25.00	30.00	33.00	27.00	25.00
Estimated Eff. Dose (mSv)	1.32	2.52	1.96	1.32	1.54	1.32	1.25
Dose w. score	20.52	13.49	12.76	22.80	21.43	20.52	20.06
IQ avg. rank	1.75	1.75	1.75	1.75	1.50	1.50	1.50
IQ w score	15.43	19.43	14.29	17.14	22.00	18.00	16.67
Final score	35.95	32.92	27.04	39.94	43.43	38.52	36.73
Rank	**5**	**6**	**7**	**2**	**1**	**3**	**4**

- The number one ranked child protocol was protocol 7:
  - 110 kV
  - 40 mAs
  - Single collimation: 1 mm
  - Pitch: 1.5
  - Slice width : 5mm

Results:
8. VGC Analysis

- The final scores were ranked, where the number one ranking protocol has the highest final score

ADULT	Protocol No.			
	1	**4**	**5**	**8**
Sum of scores	32	37	30	30
Estimated Eff. Dose (mSv)	1.03	3.63	3.74	2.97
Dose w. score	30.95	10.19	8.02	10.10
IQ avg. rank	1.75	1.5	1.5	1.5
IQ w score	18.29	24.67	20	20
Final score	49.23	34.86	28.02	30.10
Rank	**1**	**2**	**4**	**3**

- The number one ranked adult protocol was protocol 1, the protocol recommended by Siemens Applications Guide:
    - 110 kV
    - 100 mAs
    - Single collimation: 2 mm
    - Pitch: 1.5
    - Slice width: 5 mm

Discussion

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- Provisionally optimal protocols for patients less than 20 kg and greater than 20 kg have been determined
- The protocol for <20 kg IS 110 kV, 40 mAs with AEC
  - compares favourably with recommended parameters from literature.
  - The settings recommended by Siemens are 110 kV, 50 mAs with AEC, which is comparable.
  - CTDIvol is 0.76 mGy
- The protocol for >20 kg is 110 kV and 100 mAs with AEC
  - The same as the protocol recommended by Siemens
  - CTDIvol is 0.74 mGy
- The calculated estimated effective doses as a function of age for the child protocol is 1.54 mSv and 1.03 mSv for the adult protocol [11]
- The associated relative excess risk is 14.7% for males and 23.1% for females for the child protocol and 8.0% for males and 11.3% for females for the adult protocol
- It was not possible to investigate AC images as raw data was lost

Conclusions

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- An optimisation study for paediatric CT has been performed for a new SPECT/CT system in a paediatric hospital
- A method for the initial optimisation of diagnostic/ localisation quality CT that requires minimal input from radiologists has been developed that considers the calculated effective dose and physical image quality measurements of possible protocols
- Departmental $CTDI_{vol}$ reference values for a range of patient weights were defined
- Only one set of scores was returned - ideally scores would be obtained from a large number of radiologists to produce a more statistically powerful result

Future Work

- Investigate varying kV for AC using SPECT phantom for different energy isotopes
- Investigate varying reconstruction field of view and iterative reconstruction algorithms to improve resolution and low contrast detectability
- Set DRLs following dose audit
- Produce generic optimisation protocol for different SPECT/CT investigations

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Thank you for listening

Do you have any questions?

References

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[7] - SPR, AAPM, ACR, and ASRT, “Image Gently Development of Pediatric CT Protocols 2014,” pp. 1–10, 2014.

[8] - Image Gently, “IG CT PPT Tables.” 2014.

[9] - European Commission, “*European Guidelines on Quality Criteria for Diagnostic Radiographic Images”*. 1996.

[10] – M. Båth, L. G. Månsson, “Visual grading characteristics (VGC) analysis: a non-parametric rank invariant statistical method for image quality analysis,” *The British Journal of Radiology*, vol. 80,pp. 169–176, 2007

[11] - B. F. Wall, R. Haylock, J. T. M. Jansen, M. C. Hillier, D. Hart, and P. C. Shrimpton, *Radiation Risks from Medical X-ray Examinations as a Function of the Age and Sex of the Patient*, no. October. 2011.

Reference $CTDI_{vol}$

Age (years)	Effective diameter (cm)	Conversion factor	Limited SSDE (mGy)	Ref CTDIvol (mGy)
0	11.2	2.45	3	1.22
1	15.1	2.13	4	1.88
2	16.8	2.01	4	1.99
3	17.6	1.94	4	2.06
4	18.1	1.91	4	2.09
5	18.5	1.87	4	2.14
6	19	1.84	4	2.17
7	19.6	1.81	4	2.21
8	20.2	1.76	5	2.84
9	20.9	1.73	5	2.89
10	21.6	1.67	5	2.99
11	22.4	1.63	5	3.07
12	23.2	1.59	6	3.77
13	24.1	1.52	6	3.95
14	25	1.48	6	4.05
15	26	1.43	6	4.20