The Use of PCXMC in the Optimisation of Pelvic CBCT in Radiotherapy

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NHS Tayside

Overview

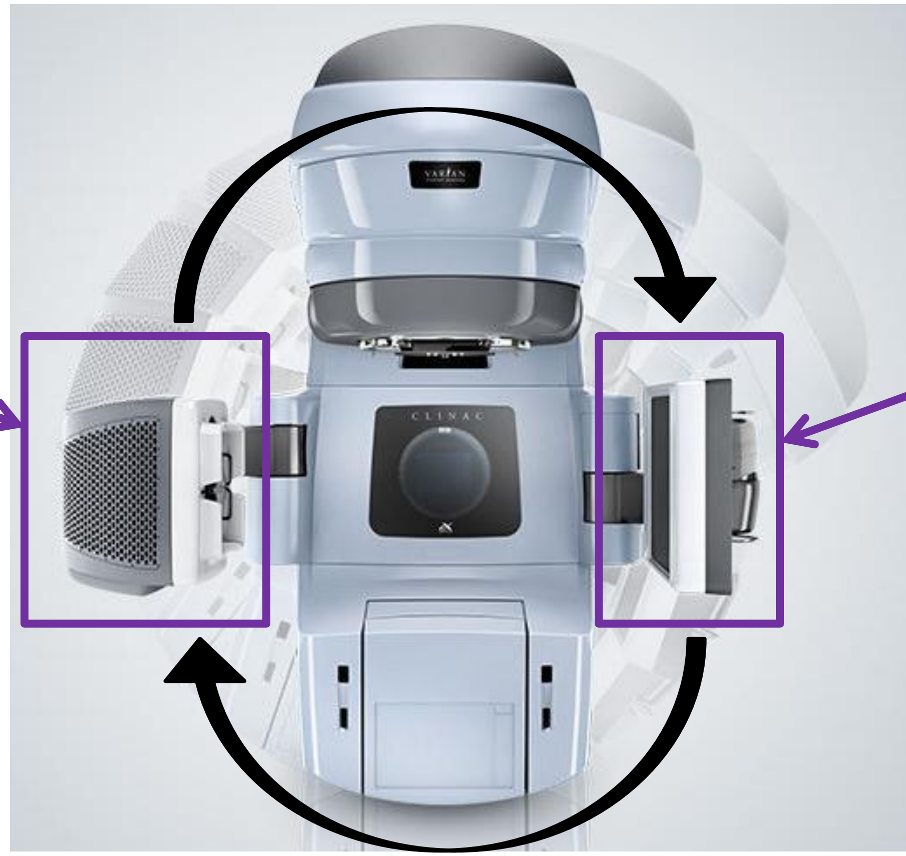
- **Objective**
  - Create size-specific pelvic CBCT protocols for OBIs on both Varian Clinac and TrueBeam linear accelerators, in order to reduce imaging dose for smaller patients.

- **Motivation**
  - Under IR(ME)R legislation have to ensure imaging doses are both justified and optimised.
  - Imaging dose can no longer be considered negligible in comparison to treatment dose.
  - Pelvic CBCT scans currently performed using Varian default protocols.

Overview

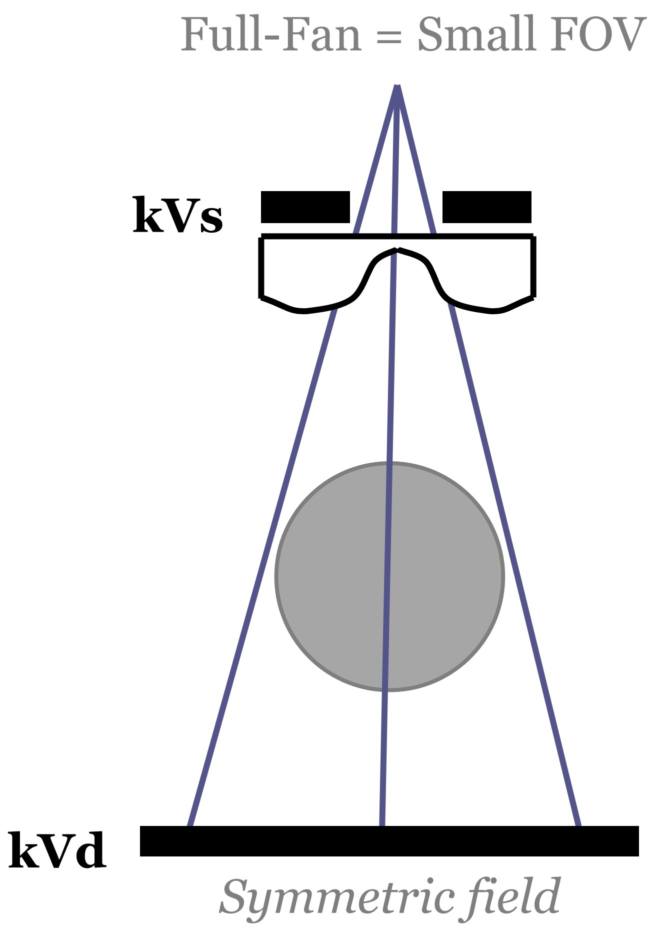
- **Issues**
  - Currently no standard approach for CBCT dosimetry or image quality assessment.
  - Pelvic CBCT acquisition differs between Varian Clinac and Varian TrueBeam accelerators
- **Goals**
  - Determine patient size categories for patients receiving pelvic CBCTs in NHS Tayside.
  - Establish method of assessing CBCT dose, for all size categories, using PCXMC.
  - Determine effect of changing exposure parameters on CBCT image quality, for all size categories.

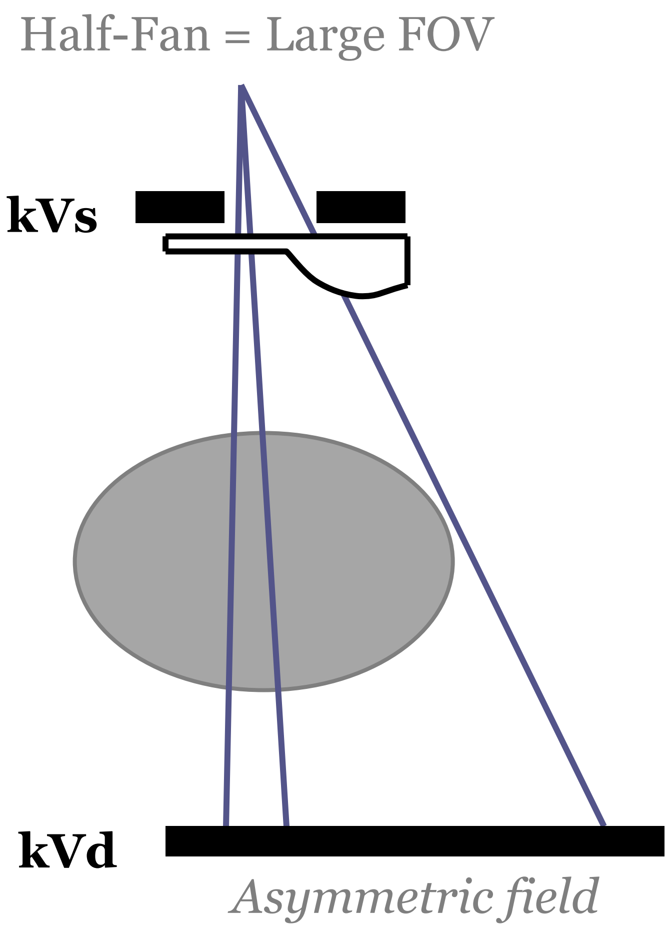
Varian OBI



Varian Clinac iX Linear Accelerator
with On-Board Imager (OBI)

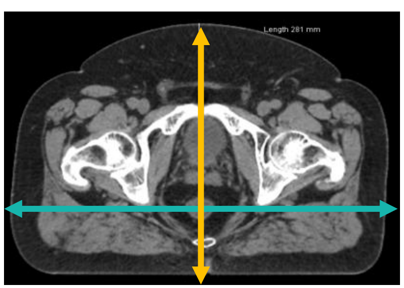
CBCT Theory


Full-Fan = Small FOV
kVs
kVd
Symmetric field

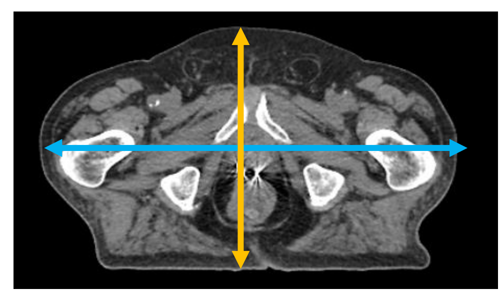

Half-Fan = Large FOV
kVs
kVd
Asymmetric field

CT Patient Audit

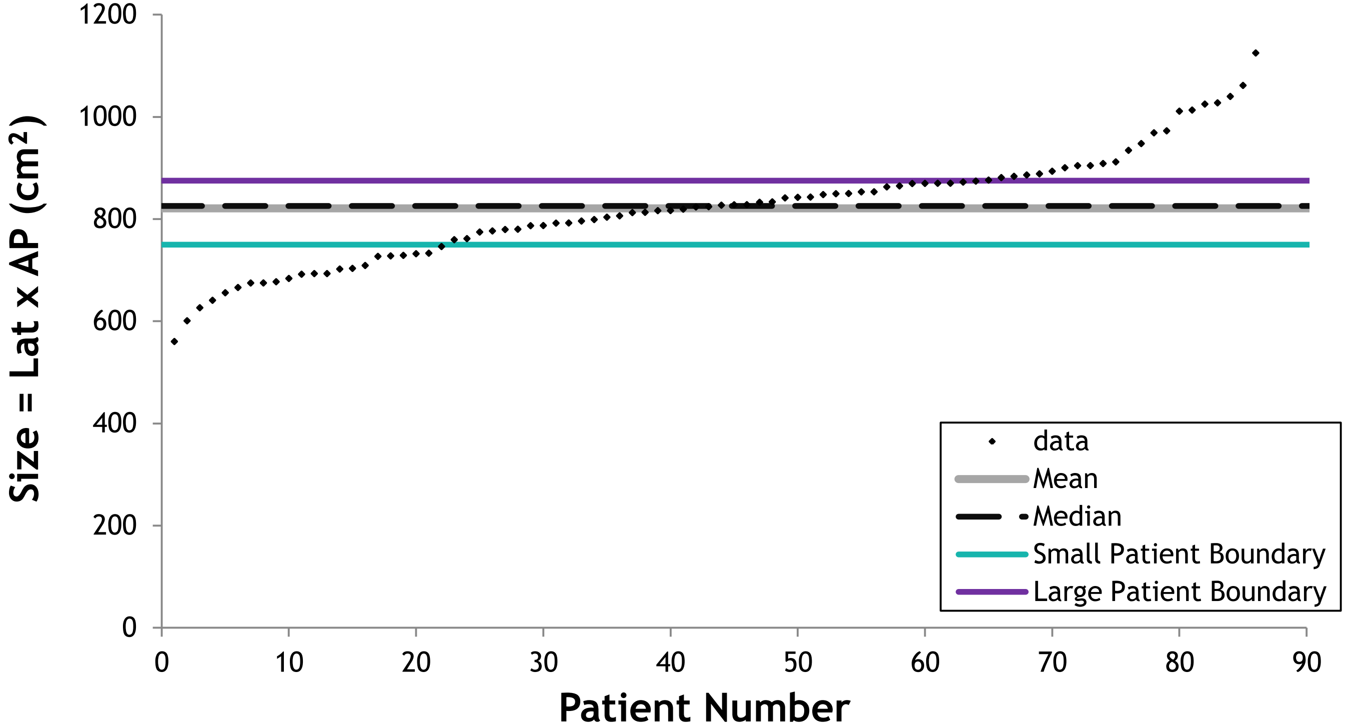
- Retrospective audit of prostate planning CTs (n=90)
- Information recorded:
  - Patient age at time of scan
  - Total scan mAs
  - Max $CTDI_{vol}$ for scan
  - Scan DLP
  - Max Lateral and A-P dimensions at position of prostate
- Due to replacement of current CT scanner, decision was made to calculate patient ‘size’ based on measurements of lateral and anterior-posterior (A-P) dimensions on the CT slice at the prostate with largest body cross-section. This will change to scan mAs or CTDI once enough data is collected for the new scanner.



‘size’ = Lateral x A-P



Patient Size Categories



Patient size Category	Calculated 'size'	Scan mAs	Scan $CTDI_{vol}$
Small	< 750 cm²	< 4780 mAs	< 45 mGy
Medium	750 – 875 cm²	4780 – 6830 mAs	45 – 70 mGy
Large	> 875 cm²	> 6830 mAs	> 70mGy

Image Quality Assessment

- Imaging radiographers reviewed 14 pelvic CBCT scans of patients representing a spread of patient sizes (5 small, 6 medium, 3 large)
- CBCTs were scored according to image quality, focusing on suitability for image matching

CBCT Image Quality Assessment - Score Sheet

Five point scale: 1 = Unacceptable 2 = Substandard 3 = Acceptable 4 = Above Average 5 = Superior

Please use your preferred window and level settings and compare the CBCT image to the planning CT.
Using the five point scale, could you please generally score in terms of the image quality (IQ) for matching with planning CT.

CHI	PTV Borders Match (1-5)	Soft Tissue Match (1-5)	Bony Anatomy Match (1-5)	Sharpness (1-5)	Contrast (1-5)	Artefacts Present (Y/N)	Overall IQ For Matching (1-5)	Comments on Overall IQ for Matching	Comments on Reason for Scores of 1 or 2

- Found to have 'acceptable' image quality for all patient size groups
  - **Large** patient size category assigned to Varian default pelvic CBCT protocols
  - Can reduce current imaging dose for smaller patients by adjusting kV and/or mAs of default pelvic CBCT protocols

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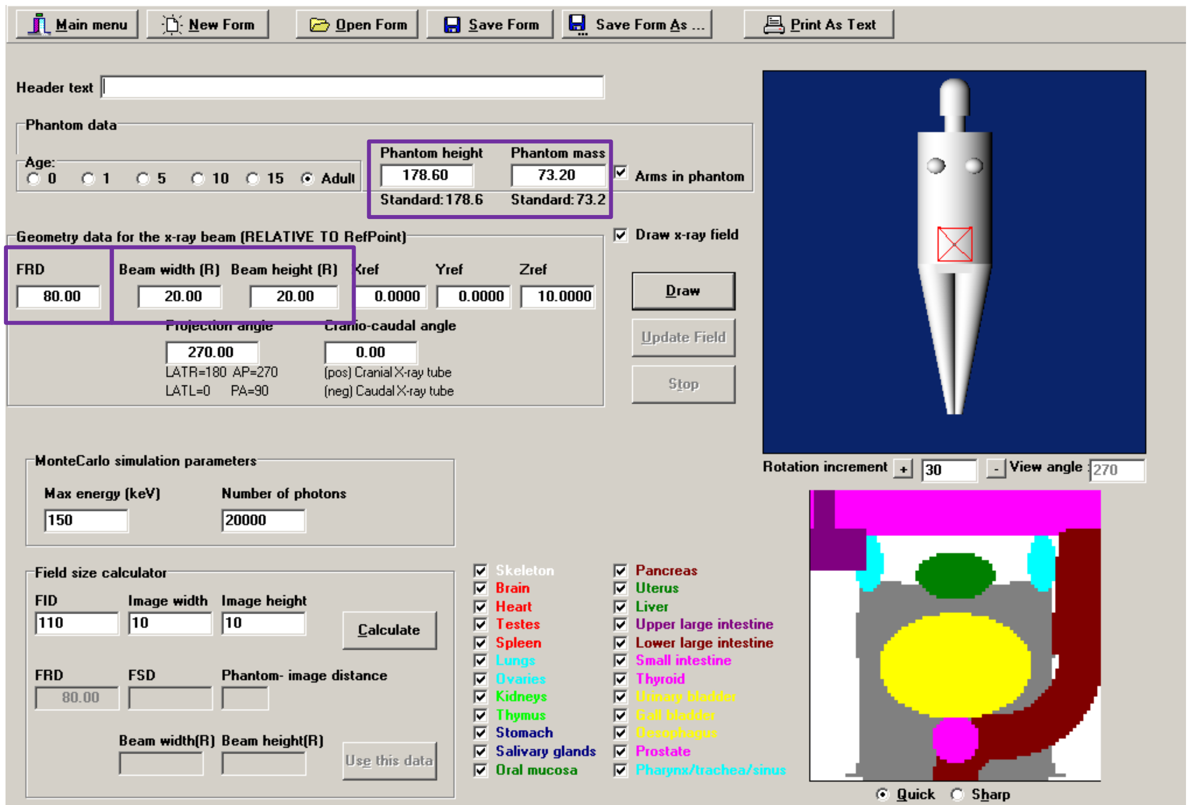
PCXMC2.0Rotation

PCXMC = **PC** program for **X**-ray **M**onte **C**arlo



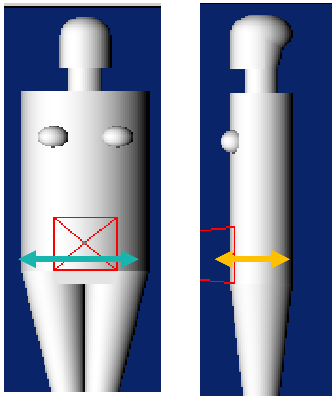
Input Height and Weight

PCXMC Phantom Height

- Decided to set a phantom height of **175cm** for all patient size categories

PCXMC Phantom Weight

- Increased phantom weight from 58kg to 95kg
- Measured phantom lateral and A-P dimensions for each input weight
- Calculated a 'size' for each input weight
- From range of weights for each size category, **median** weight was decided on for PCXMC input



Size Category	Height (cm)	Weight (kg)
Small	175	63
Medium	175	78
Large	175	90

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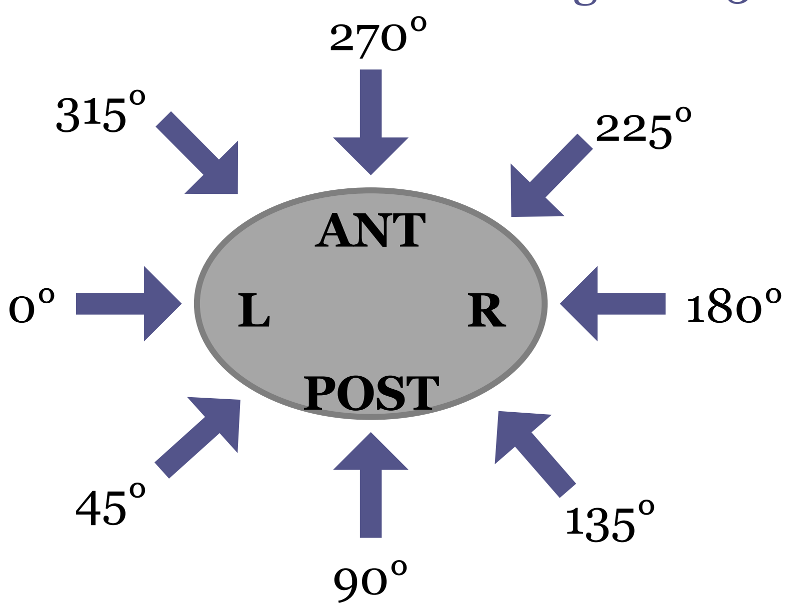
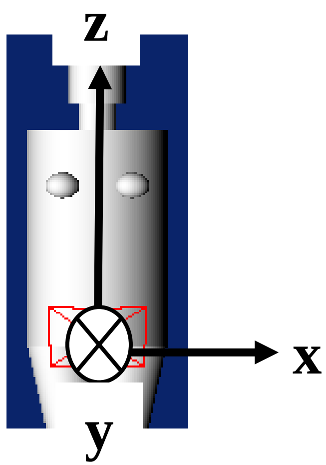
Number of Projections

- For 360° pelvis CBCT scan the OBI acquires 655 projections (Clinac) or 900 projections (TrueBeam)
  - Not practical to model this as computation time too long
- Previous project within department recommended using **8** equally spaced projection angles for modelling effective dose in the pelvic region
  - No additional benefit found from using 16 or 32 projections



Reference Co-ordinates

- Pelvic CBCT acquired with asymmetric beam and the detector off-set
- PCXMC models symmetric beams, therefore reference co-ordinates were determined in order to model an asymmetric beam

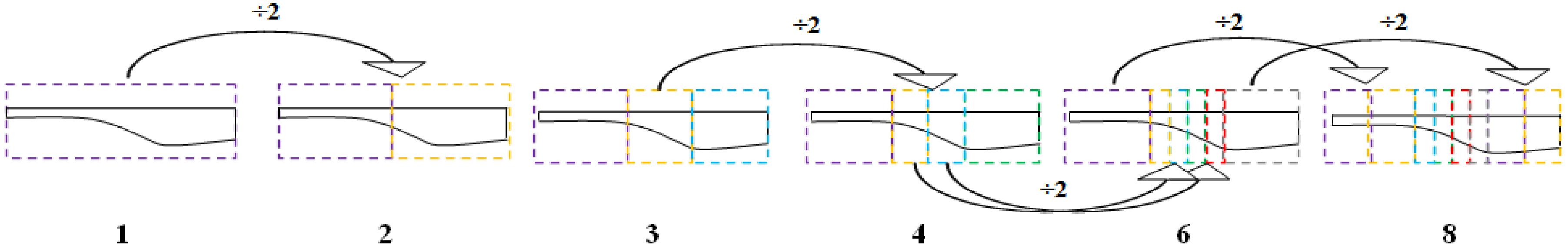


X_{ref} and Y_{ref} - Off-set direction changes depending on projection angle

Z_{ref} - Same for all projections. Positioned at level of prostate based on organs in FOV

Number of Sub-Fields

- PCXMC assumes a uniform x-ray spectra; however due to half-fan bow-tie filter, pelvic CBCT beam is not uniform
- Due to the half-fan bow-tie filter used for pelvic CBCT scans, it was decided to split the beam into sub-fields, each of which will be considered 'uniform'
- An investigation determined that the optimal number of sub-fields to use is **4**



- Using more than 4 sub-fields resulted in no change of effective dose, but increased computational complexity

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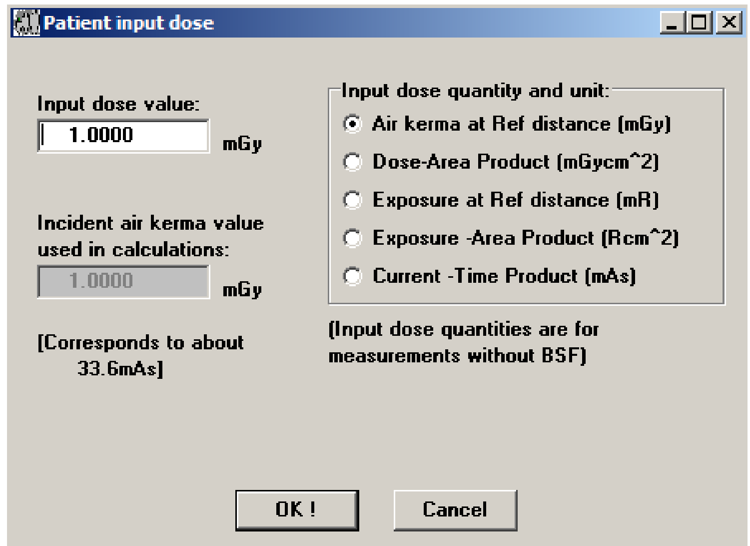
DAP vs. Air Kerma



- 5 input dose quantities available in PCXMC
- Decided to compare:
  - Air Kerma at reference distance (*i.e.* isocentre) in mGy
  - Dose-Area Product (DAP) in $mGy.cm^2$

Air Kerma Measurements

Set-Up

- Gantry at 90°
- Half-fan bow-tie filter inserted into kVs
- kVs at 0° and positioned at +100cm
- kVd at 180° and positioned offset at -50cm
- Treatment couch within OBI field of view
- Asymmetric field as used in CBCT protocol

Successful Method

- RadCal 10X6-6 ionisation chamber with traceable kV calibration
- Detector positioned in air at isocentre
- Air kerma recorded in centre of all 4 sub-fields
- Measurements taken for both 110kV and 125kV

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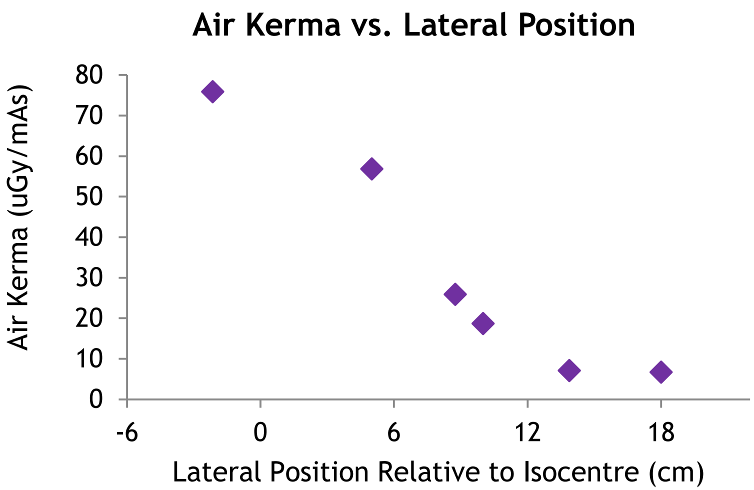
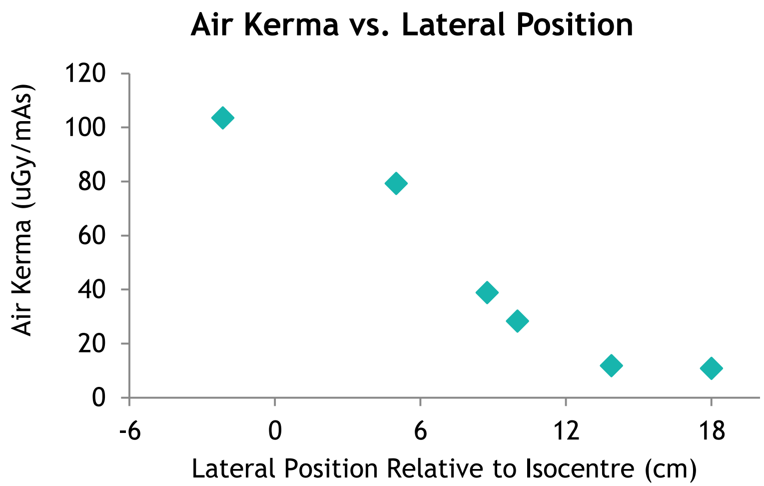
Air Kerma Results (Clinac)

110kV

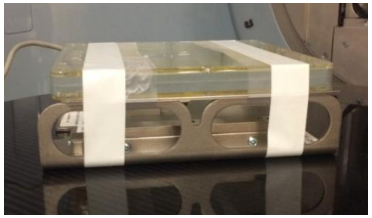


125kV



Sub-Field	Lateral Position (cm)	Air Kerma for 110kV		Air Kerma for 125kV	
		µGy/mAs	mGy	µGy/mAs	mGy
1	-2	75.9	6.46	103.6	8.82
2	5	56.9	4.84	79.3	6.75
3	9 10	25.9 18.7	2.21 1.59	38.9 28.4	3.31 2.41
4	14 18	7.1 6.7	0.60 0.57	11.9 10.9	1.01 0.92

DAP Measurements (Clinac)



Set-Up

- Same as for air kerma measurements

Method

- PTW Diamentor M2 DAP meter attached to half-fan bow-tie filter
- Filter and DAP meter assembly inserted into kVs
- RadCal Patient Dose Calibrator, traceable to National standard, positioned on treatment couch
- RadCal used to calibrate PTW DAP meter
- PTW DAP meter used to record full-field DAP for 100mAs exposure
- Measurements taken for both 110kV and 125kV

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DAP Results (Clinac)

- To get correction for field non-uniformity due to half-fan bow-tie filter, XR-QA2 Gafchromic film was irradiated using the same set-up
- Film was processed and dose profile for filter obtained
- Dose profile used to get percentage of total DAP per sub-field
- DAP per sub-field then determined for PCXMC input

Thick end of filter
= ↓ *exposure*

Thin end of filter
= ↑ *exposure*

Sub-Field	Lateral Position (cm)	% of Full Field DAP	DAP for 110kV mGy/cm²	DAP for 125kV mGy/cm²
1	-2	57.09	75.9	103.6
2	5	23.84	56.9	79.3
3	9 10	6.52 9.77	25.9 18.7	38.9 28.4
4	14 18	1.98 6.86	7.1 6.7	11.9 10.9

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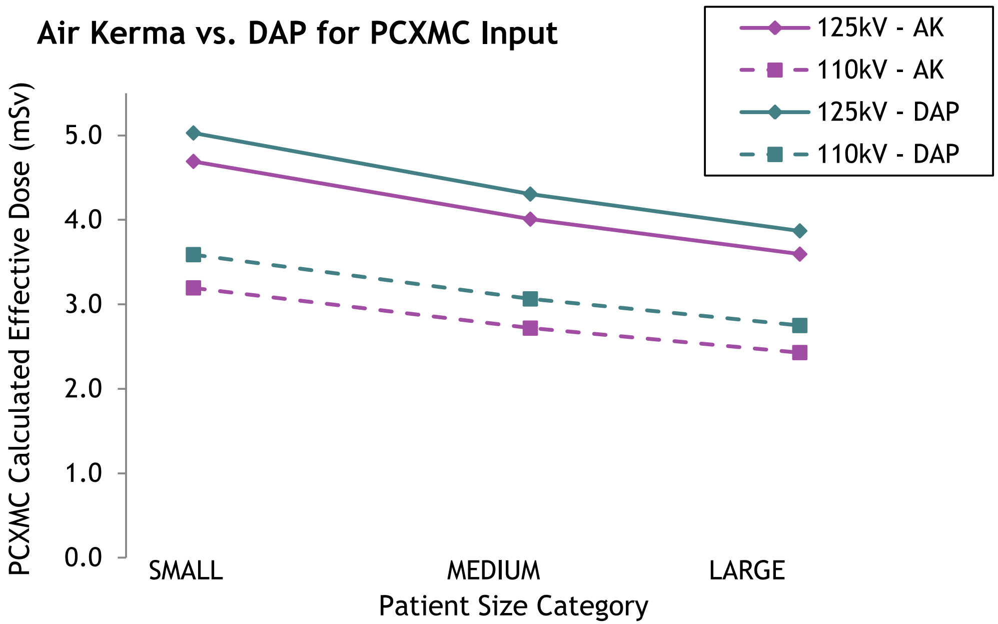
DAP vs. Air Kerma (Clinac)



- Both inputs show the same trend with respect to patient weight and change in kV
- Effective dose calculated via DAP input is consistently higher than for Air Kerma input
  - Uncertainty in detector positioning for Air Kerma measurements taken to contribute to difference

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Quantifying Imaging Dose (Clinac)

	PCXMC Determined Effective Dose (mSv)		
CBCT Exposure Setting	Small	Medium	Large
125kV, 80mA, 13ms	5.03	4.30	3.87
125kV, 63mA, 13ms	3.96	3.39	3.04
125kV, 50mA, 13ms	3.14	2.69	2.42
125kV, 40mA, 13ms	2.51	2.15	1.93
110kV, 80mA, 13ms	3.59	3.06	2.75
110kV, 63mA, 13ms	2.82	2.41	2.16
110kV, 50mA, 13ms	2.24	1.91	1.72
110kV, 40mA, 13ms	1.79	1.53	1.37

- PCXMC simulations, using DAP as dose input, indicate patients receive an effective dose ranging from **3.87mSv to 5.03mSv** for the current default protocol (125kV, 80mA, 13ms).

- Evident that the effective dose for smaller sized patients can be reduced by decreasing the tube voltage or scan mA.

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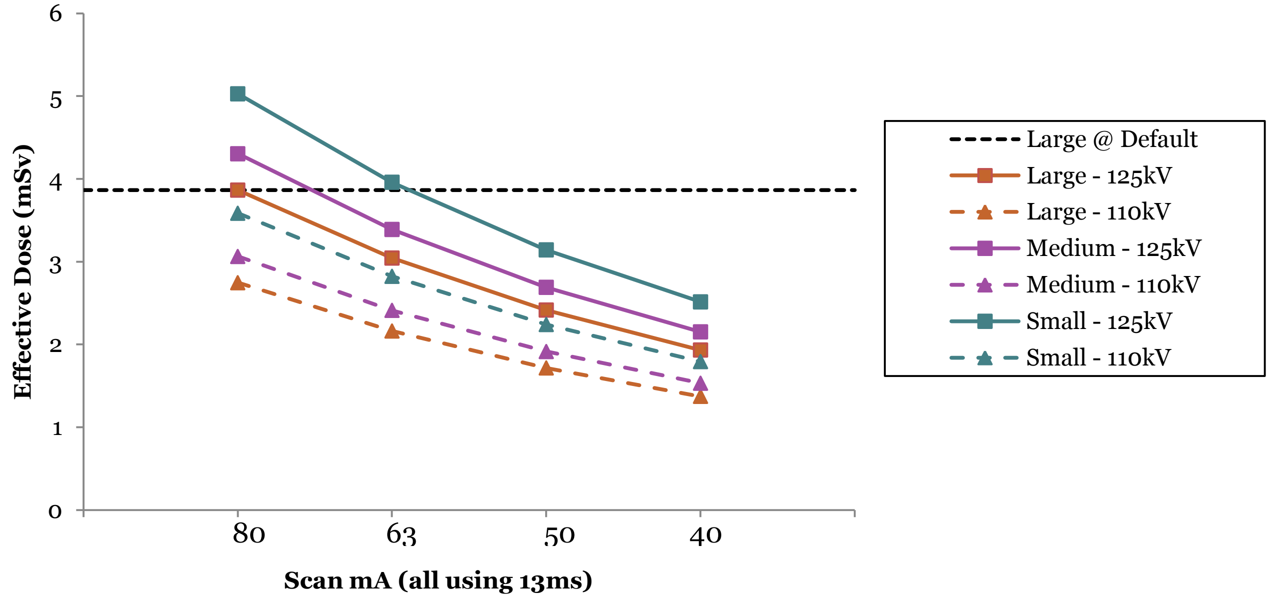
Size-Specific Protocols (Clinac)

- Size-specific protocol settings selected with intention of all sized patients receiving equivalent CBCT dose



Patient Size Category	CBCT Exposure Setting	Change in Dose wrt Current Protocol
Small	125kV, 50mA, 13ms 110kV, 80mA, 13ms	-37.6% -28.6%
Medium	125kV, 63mA, 13ms	-14.8%
Large	125kV, 80mA, 13ms	N/A

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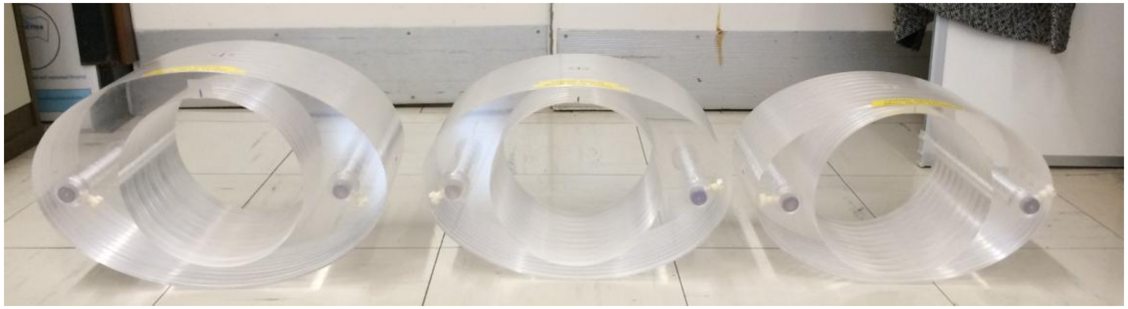
Image Quality

- In-house constructed size-category specific Catphan annuli were created to verify the image quality for the new pelvic CBCT protocols



- All annuli were designed to slip over 20cm outer diameter Catphan phantoms.

- Using data from the CT patient audit, the largest size of a patient within each category was used to define the outer dimensions of the annuli. This was in order to determine the 'worst case' image quality in each category.

Annulus Size	Height (cm)	Width (cm)	Length (cm)
Small	22	34	20
Medium	24	36.5	20
Large	26	39	20

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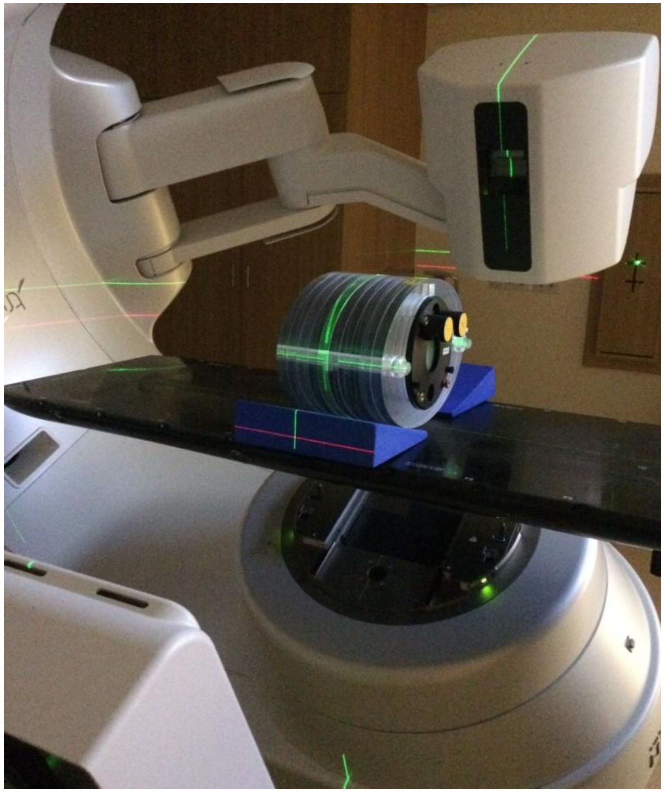
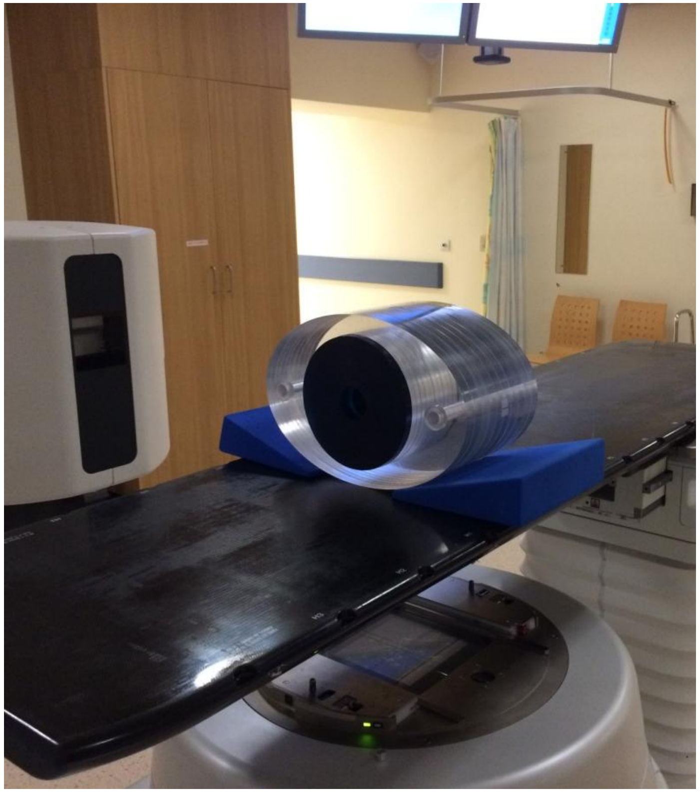
Image Quality

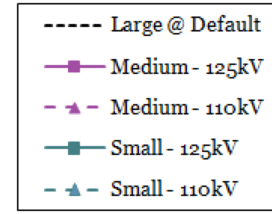


Align with in-room lasers

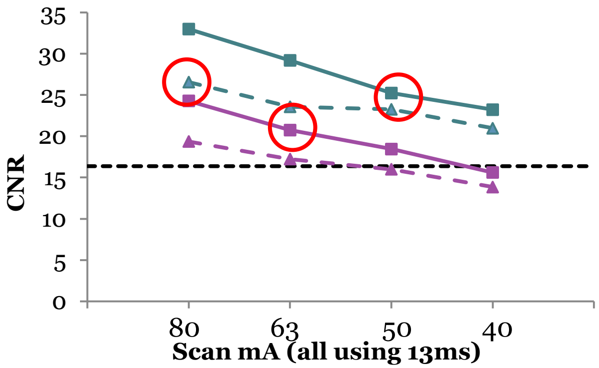


Use soft wedges to aid positioning

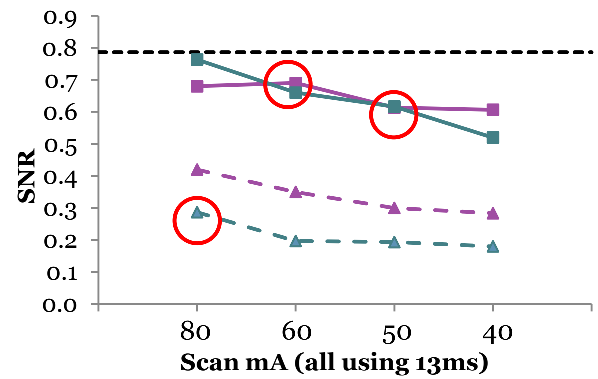
Image Quality (Clinac)



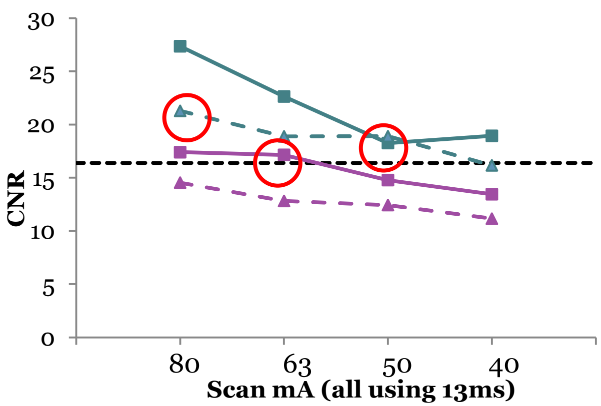
- CNR (Air and BG)



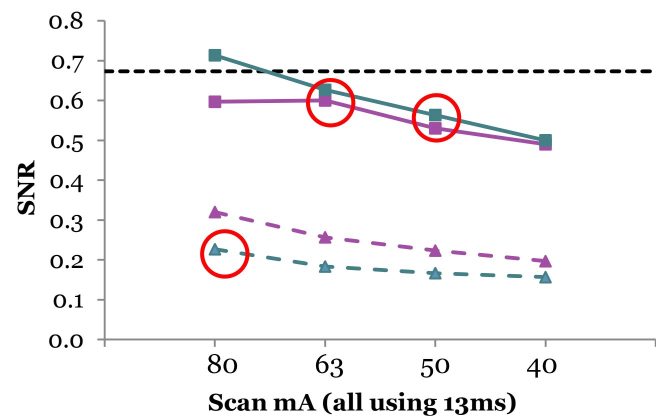
- SNR (Large ROI)



- CNR (Telfon and BG)



- SNR (Small ROIs)



Summary

- PCXMC pelvic CBCT model successfully created using **8** projections and **4** sub-fields per projection

- **DAP** was chosen as the optimal PCXMC dose input for pelvic CBCTs
  - Removes uncertainty with positioning associated with Air Kerma measurements

- Based on this study, **3** size-specific pelvic CBCT protocols will be implemented in NHS Tayside for the Varian OBIs

- The Varian default protocol will be used for the **large** patient size category
  - Imaging dose will be reduced for the small and medium size groups by adjusting mA

- Image quality results using the Catphan plus annulus confirm the image quality of new protocol settings are comparable to that of the default for the large size category.

- Initial clinical implementation results indicate new protocols are clinically useable and not detrimental to clinical decision making.
  - In the future there may be scope to reduce imaging dose further

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Thanks

- Emma McIntosh, Radiotherapy Physicist
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- Kirsty Muir, Treatment Advanced Practitioner
- Ian Sanders, Oncology Consultant

Key References

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Thank you for listening.

Are there any Questions?