University Hospitals Coventry and Warwickshire NHS Trust

Implementation of Cone-beam CT imaging for Radiotherapy treatment localisation.

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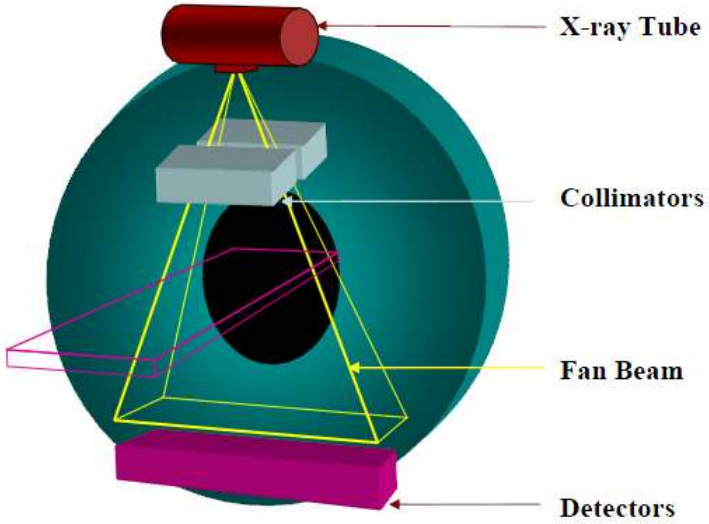
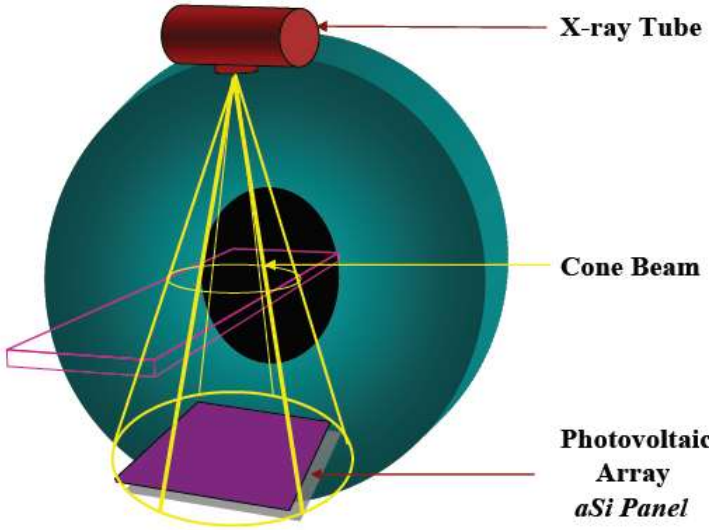
Overview

- What is CBCT?
- Use of CBCT in Radiotherapy
- Dosimetry
- Concomitant Doses
- Issues with CBCT Dosimetry
- Image Quality
- Protocol Optimisation

Fan beam vs Cone beam





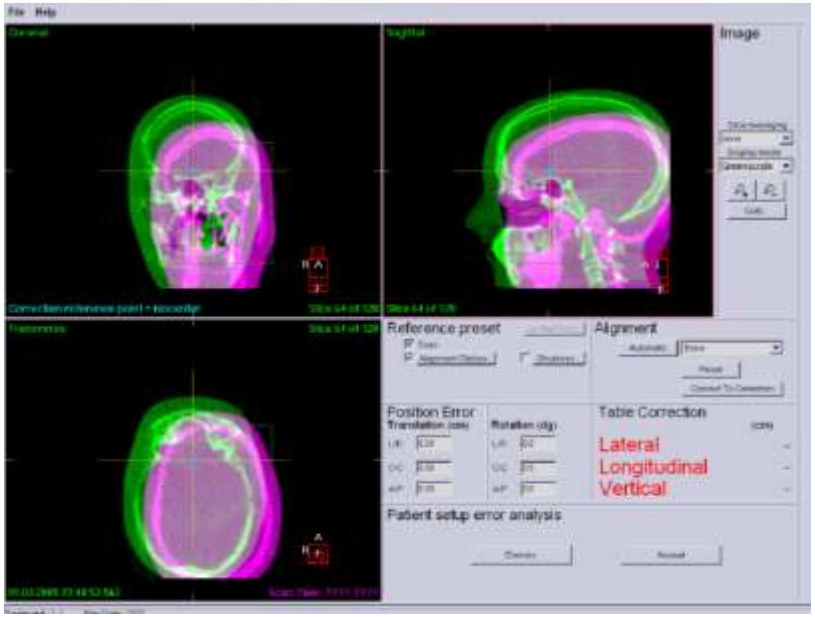
Use of kV CBCT

- Radiology:
  - Interventional Radiology: Rotation angiography
  - Orthopaedics: Pelvis fractures & Hip Dysplasia

- Radiotherapy ???
  - Image guided radiotherapy: H&N, Chest, Pelvis, etc.

Why is it used in Radiotherapy?

- Localisation of tumours required to ensure accurate delivery of treatment.
- Planar MV imaging provides limited localisation using bony anatomy.
- Unable to correct for tumour motion between fractions and so causes loss of tumour control and increased normal tissue irradiation.
- kV imaging provides soft tissue contrast and comparison with planning CT
- This allows the treatment to be corrected for the tumour motion.



Situation at UHCW

- Two Elekta Linear Accelerators fitted with Synergy XVI kV Cone-beam systems.
- Use of these linear accelerators is targeted at Head & neck (limited margins) and prostate (organ motion) patients.
- Patients are scanned daily and image registration is carried out between planning CT and CBCT.
- The image registration matches bony anatomy and Soft tissue structures between the two data sets – automated mostly. (‘Grey level’ matching)
- Registration is reviewed and the table corrections are applied.
- If table correction is greater than 10mm in any one direction, then this is reviewed by the Oncologist and a Radiotherapy Physicist; this may require a re-plan.

Commissioning

- Follows similar testing as other diagnostic imaging equipment:
  - Tube & Generator – Performance in Planar mode, HVL, Field Sizes
  - Dosimetry – $CTDI_{air}$, $CTDI_{w}$.
  - Image Quality – Spatial Resolution & Contrast Visibility.
  - Radiation Protection – Critical Exam, Leakage, Control measures
  - Geometric alignment.
  - Defining Presets – Scanning Protocols

Further details: Lehmann, J., et al., *Commissioning experience with cone-beam computed tomography for image-guided radiation therapy. J Appl Clin Med Phys, 2007. 8(3): p2354*

Dosimetry?

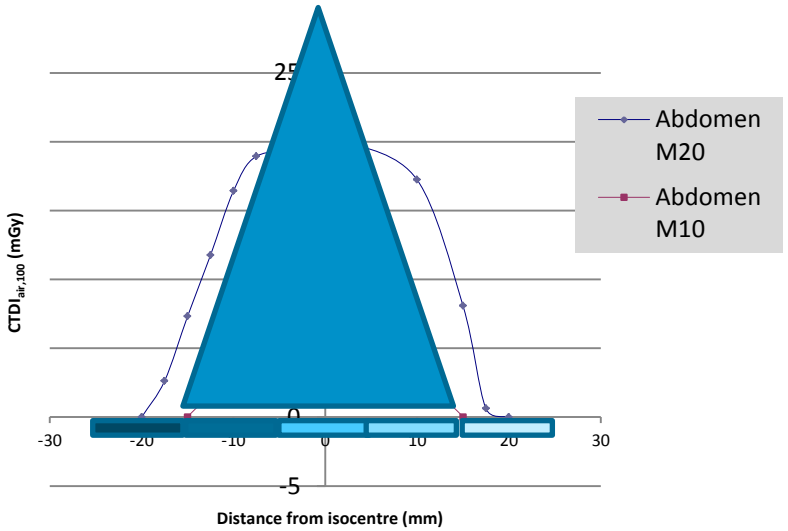
- Breakdown of CTDI100 with wider collimations >40mm.
- XVI CBCT collimation >13.5cm
- Guidance: AAPM TG111, IAEA Human Health Report 5, etc.
- Recently reviewed (post-commissioning):

CTDI

- Each protocol was assessed following the IAEA $CTDI_{free\text{-}in\text{-}air}$ method with a 3.2cc pencil CT chamber (100m length).

$$CTDI_{Free-in-air} = \frac{L}{N \times T} \sum_{i=1}^{i=n} D_i$$

- L = incremental movement
- Stepped Movement of chamber through cone-beam field of view using accurate table movements.



Collimator	Bow-tie Filter	kV	$CTDI_{air,normalised}$ (mGy)
S10	F1	100	2.74
S20	F1	100	2.8
M10	F1	120	4.43
M20	F1	120	4.54

Pelvis M20 Protocol measurement

Displacement of chamber (mm)	100	50	25
L/NxT	0.36	0.18	0.09
$\sum D_i$ (mGy)	53.1	106.5	209.3
$CTDI_{air}$ (mGy)	19.3	19.4	19.0

CTDI cont'd

- CTDIw measurements carried out using 16/32cm PMMA phantom.
- Limited width of phantom (~15cm), approx. to S/M10 collimators.
- Addition of PMMA next to phantom to provide additional scatter.
- S/M10 ~ 1% & S/M20 ~ 6%

Anatomy	Collimator	kV	Elekta Presets	
			mAs	$CTDI_w$ (mGy)
Head & Neck	S10	100	36.6	0.6
Head & Neck	S20	100	36.6	0.7
Chest	M20	120	1056	20.1
Pelvis	M10	120	1056	16.7
Pelvis	M20	120	1056	20.1
Prostate	M10	120	1690	26.8
Prostate	M20	120	1690	32.1

CTDI cont'd

Issues with both CTDI measurements were found, in particular tube cooling.

- For CTDIair, rotational & static (Planar) measurements were made. Static measurements approx. 12% greater than rotational.
- For $CTDI_w$, the 32cm Phantom required significantly higher exposure parameters due to problems with continuous exposure of the chamber on the periphery.

Why do concomitant doses matter?

Legally, IRMER 2000 requires Justification

- Justification should occur for each individual patient, based on the risk and benefit of the examination. Therefore, impact of daily CBCT needs to quantified.
- Allows comparison between imaging used within the treatment pathway – Planning CT, Portal (MV) imaging & CBCT

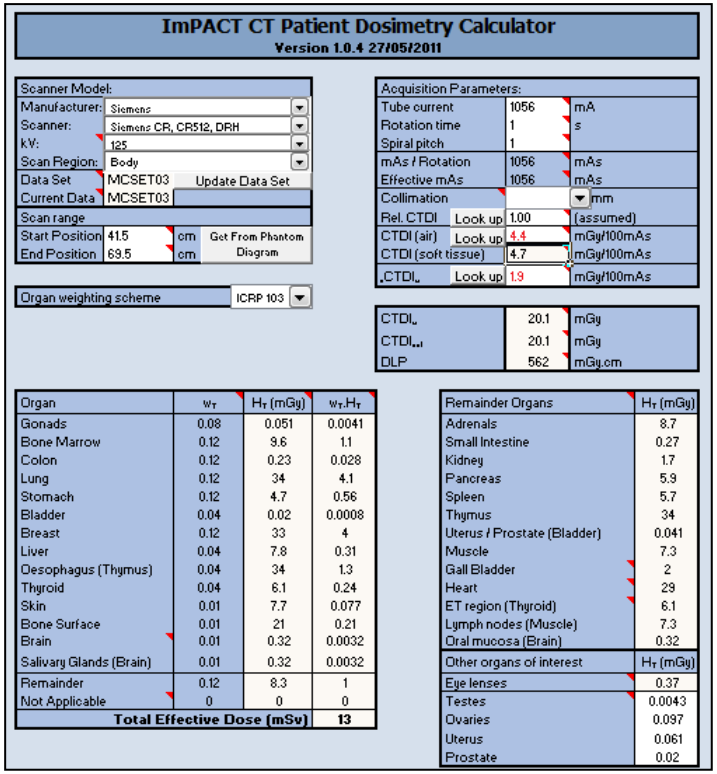
Practical reason - Provides dose estimates for Organs At Risk (OAR).

How do we calculate them?

ImPACT Calculator (1.0.4)

- Siemens DRH (125kV)
- No selected collimation, pitch =1
- Input $CTDI_{air}$ & $_{n}CTDI_{w}$

Assessed each CBCT protocol and then proceeded to carry out the same with CT simulator protocols.



ImPACT CT Patient Dosimetry Calculator
Version 1.0.4 27/05/2011

Scanner Model:			
Manufacturer:	Siemens		
Scanner:	Siemens CR, CR512, DRH		
kV:	125		
Scan Region:	Body		
Data Set	MCSET03	Update Data Set	
Current Data	MCSET03		
Scan range			
Start Position	41.5	cm	Get From Phantom Diagram
End Position	69.5	cm	

Organ weighting scheme	ICRP 103

Acquisition Parameters:			
Tube current		1056	mA
Rotation time		1	s
Spiral pitch		1	
mAs / Rotation		1056	mAs
Effective mAs		1056	mAs
Collimation			mm
Rel. CTDI	Look up	1.00	(assumed)
CTDI (air)	Look up	4.4	mGy/100mAs
CTDI (soft tissue)		4.7	mGy/100mAs
$_{n}CTDI_{w}$	Look up	1.9	mGy/100mAs

$CTDI_{w}$	20.1	mGy
$CTDI_{vol}$	20.1	mGy
DLP	562	mGy.cm

Organ	w_T	H_T (mGy)	$w_T.H_T$
Gonads	0.08	0.051	0.0041
Bone Marrow	0.12	9.6	1.1
Colon	0.12	0.23	0.028
Lung	0.12	34	4.1
Stomach	0.12	4.7	0.56
Bladder	0.04	0.02	0.0008
Breast	0.12	33	4
Liver	0.04	7.8	0.31
Oesophagus (Thymus)	0.04	34	1.3
Thyroid	0.04	6.1	0.24
Skin	0.01	7.7	0.077
Bone Surface	0.01	21	0.21
Brain	0.01	0.32	0.0032
Salivary Glands (Brain)	0.01	0.32	0.0032
Remainder	0.12	8.3	1
Not Applicable	0	0	0
Total Effective Dose (mSv)			**13**

Remainder Organs	H_T (mGy)
Adrenals	8.7
Small Intestine	0.27
Kidney	1.7
Pancreas	5.9
Spleen	5.7
Thymus	34
Uterus / Prostate (Bladder)	0.041
Muscle	7.3
Gall Bladder	2
Heart	29
ET region (Thyroid)	6.1
Lymph nodes (Muscle)	7.3
Oral mucosa (Brain)	0.32

Other organs of interest	H_T (mGy)
Eye lenses	0.37
Testes	0.0043
Ovaries	0.097
Uterus	0.061
Prostate	0.02

Concomitant Doses

Imaging Protocol	OAR	Organ doses (mGy)		
		Portal	XVI	CT Sim
Brain (S10)	brain	20	0.6	29
	SG	30	0.6	29
	Eyes	30	0.8	34
H&N (S20)	brain	10	0.7	31
	SG	30	0.7	31
	Spinal cord	5	-	-
	thyroid	30	0.9	43
	Eyes	30	0.8	35
	oeso	10	0.1	2
Chest (Chest M20)	oeso	10	34	39
	lungs	8	34	35
	Spinal cord	5	-	-
	stomach	5	4.8	6.9
	liver	5	8	11
	breast	7.5	34	29
Abdomen	colon	10	Not Known	23
	Spinal cord	5		-
	stomach	5		32
	liver	5		31
Pelvis (Pelvis M20)	gonads	2	18	26
	Spinal cord	5	-	-
	colon	10	25	28
	Prostate	35	29	33
	bladder	30	30	35
Rectum (Prostate M10)	colon	10	16	15
	gonads	5	35	28
	prostate	25	38	28
	bladder	20	50	31

Imaging Protocol	Effective Dose (mSv)	
	XVI	CT Sim
Brain	0.03	3
H&N	0.09	4.4
Chest	13	14
Abdo	-	17
Pelvis	8.1	9.6
Rectum	8.2	7

Problems

- H&N CBCT protocol – Half scan (200º)
- Matching of Scanners on ImPACT – Siemens DRH ~ 125kV only

Detailed information: Sykes JR et al. Dosimetry of CBCT: methods, doses and clinical consequences. Journal of Physics: Conf. Series 444 (2013)012017

Optimisation of Protocols

- Elekta provide the presets for which our calculations were completed.
- As a result of the image quality testing further dose reduction and optimisation seemed reasonable for the body protocols, in terms of Exposure and Reconstruction parameters.

Image Quality

- 2D QA – TOR18FG – Contrast & Spatial Resolution
- 3D QA – Catphan
  - Uniformity
  - Low contrast Visibility – Uses Polystyrene & LDPE in CT no. Module
  - Spatial Resolution : at least 10 lp/mm
  - Reconstruction Geometry – Axial & Sagittal
  - Registration Accuracy – MV & kV imaging – Positional marker at isocentre

- Semi-automated image analyse of catphan produced for monthly QC.

Presets

- Volume.ini
  - Imaging protocols
  - Exposure & Acq. parameters
  - Reconstruction
- Reconstruction.ini
  - Pre-filter
  - Scatter correction
  - Reconstruction Filter Parameters
- Multi-level Gain & Filter calibrations

[Pelvis M20]	Value
PresetDescription	Pelvis VolumeView
Mode	Clinical
kV	120
NominalmAPerFrame	16
NominalmsPerFrame	40
kVCollimator	M20
kVFilter	F1
StartAngle	-180
StartAcqAngle	-180
StopAcqAngle	180
GantrySpeed	180
Direction	CW
Frames	660
TableIsocentric	0
TableColumnRotation	0
DefaultReconstructionPreset	M20 - Med_Res

[M20 - Med_Res]	Value
ReconstructionVoxelSize	1.0
ReconstructionDimensionX	401
ReconstructionDimensionY	264
ReconstructionDimensionZ	410
ReconstructionOffsetX	0
ReconstructionOffsetY	0
ReconstructionOffsetZ	0
ReconstructionFilter	Wiener
NumberOfReconstructionFilterParameters	2
ReconstructionFilterParameter1	0.05
ReconstructionFilterParameter2	90
Interpolation	Partial2
ScatterCorrection	Uniform
NumberOfScatterCorrectionParameters	1
ScatterCorrectionParameter1	0.2
ReconstructionDataType	Short
PreFilter	Median 5
ProjectionDownSizeFactor	2

Optimisation of Protocols

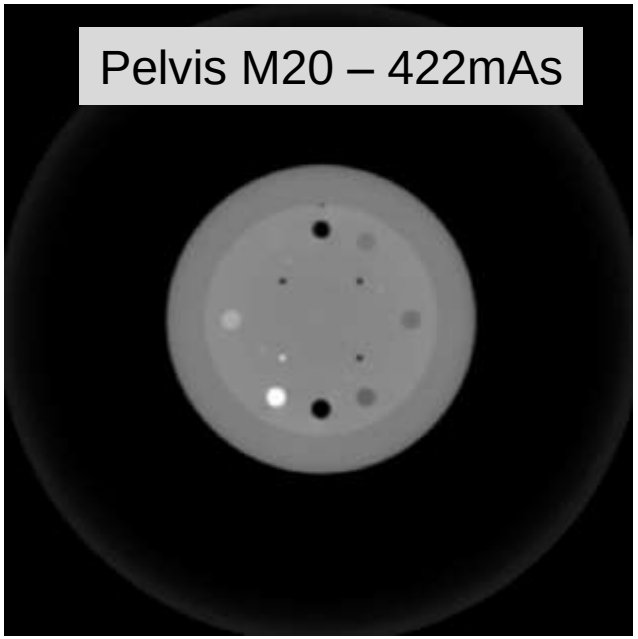
- Discussed situation with another department already using the system.
- Reduced the mA per frame to deliver this reduction, standard body protocols reduced from 40/64mA (Pelvis/Prostate) to 16 mA.

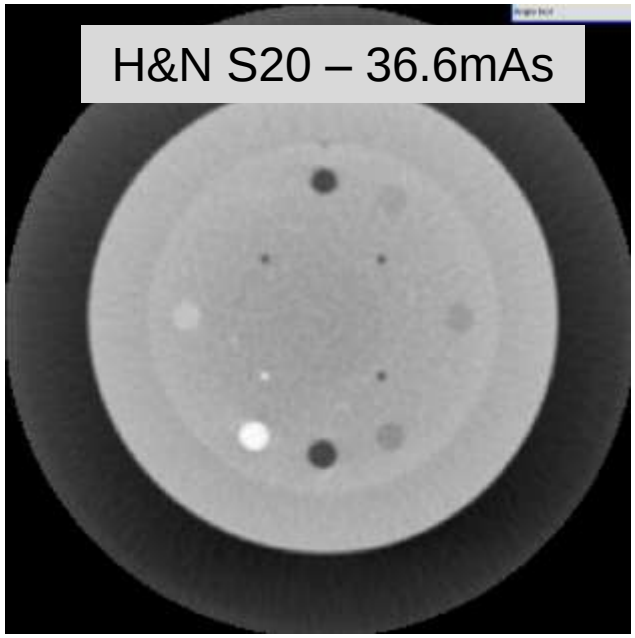
Concomitant Doses - Revised

Imaging Protocol	OAR	Organ doses (mGy)		
		Portal	XVI	CT Sim
Brain (S10)	brain	20	0.6	29
	SG	30	0.6	29
	Eyes	30	0.8	34
H&N (S20)	brain	10	0.7	31
	SG	30	0.7	31
	Spinal cord	5	-	-
	thyroid	30	0.9	43
	Eyes	30	0.8	35
	oeso	10	0.1	2
Chest (Chest M20)	oeso	10	8.5	39
	lungs	8	8.6	35
	Spinal cord	5	-	-
	stomach	5	1.2	6.9
	liver	5	2	11
	breast	7.5	8.4	29
Abdomen (Abdomen M10)	colon	10	2.2	23
	Spinal cord	5	-	-
	stomach	5	9.7	32
	liver	5	8.4	31
Pelvis (Pelvis M20)	gonads	2	7.2	26
	Spinal cord	5	-	-
	colon	10	10	28
	Prostate	35	11	33
	bladder	30	12	35
Rectum (Prostate M10)	colon	10	4.1	15
	gonads	5	8.8	28
	prostate	25	7.0	28
	bladder	20	12.5	31

Imaging Protocol	Effective Dose (mSv)	
	XVI	CT Sim
Brain	0.03	3
H&N	0.09	4.4
Chest	3.3	14
Abdo	2.6	17
Pelvis	3.3	9.6
Rectum	2.0	7

Image Quality Results from Recent QC Testing





Protocol	Collimator	Contrast Visibility	Noise (%)	Resolution (lp/cm)
Pelvis	M20	0.51	4.1	3.5
H&N	S20	1.26	19.3	2.5

Future Work……

- Review of reconstruction presets
  - Scatter correction?
  - Reconstruction Parameters 1 & 2?
- Optimise protocols appropriate for larger patients
- Confirm Organ Doses using TLDs

Acknowledgements

- Radiotherapy Physicists & Radiographers at University Hospital.