Radiation Dose in CT: Implications for PET/CT and SPECT/CT

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Typical CT doses in Australia

Exam	Adult Effective Dose mSv	5-7 year old Effective Dose mSv
Head	2.55	1.99
Chest	4.3	7.15
Abdomen	12.73	12.47

M Moss and D McLean – Paediatric and Adult CT Practice and Patient Dose in Australia – Australian Radiology (2006) **50**, 33-40

Typical Nuclear Medicine Doses in Australia

Procedure (Adult ref activity)	Adult Dose mSv	19.8 kg weight scaled Dose mSv
In111/Octreotide (200 MBq)	10.8	9
Ga67 (200 MBq)	30	27.7
F18 (400MBq)	7.6	5.6
Tc99m – Bone (900 MBq)	4.3	2.9

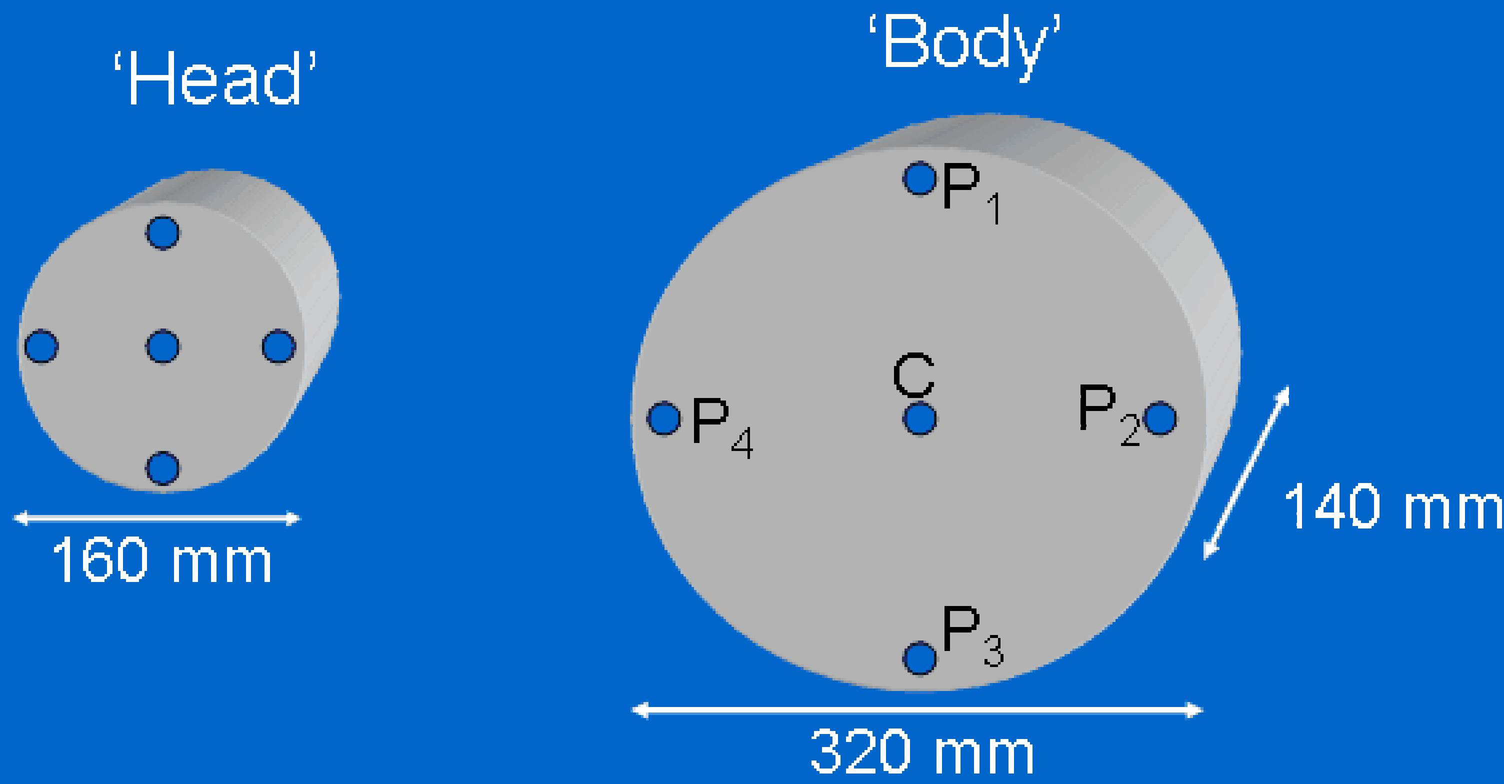
ANZSNM/ARPS Survey 1999/2000 and ICRP53

Dosimetry Basics

- To relate patient doses to scanning parameters we need to have a basic understanding of what measurements are made and how they relate to patient dose.
- The second party of the process is to see what effect changes in scan conditions have on dose.
- The crucial step however is whether the images produced provide the information needed.

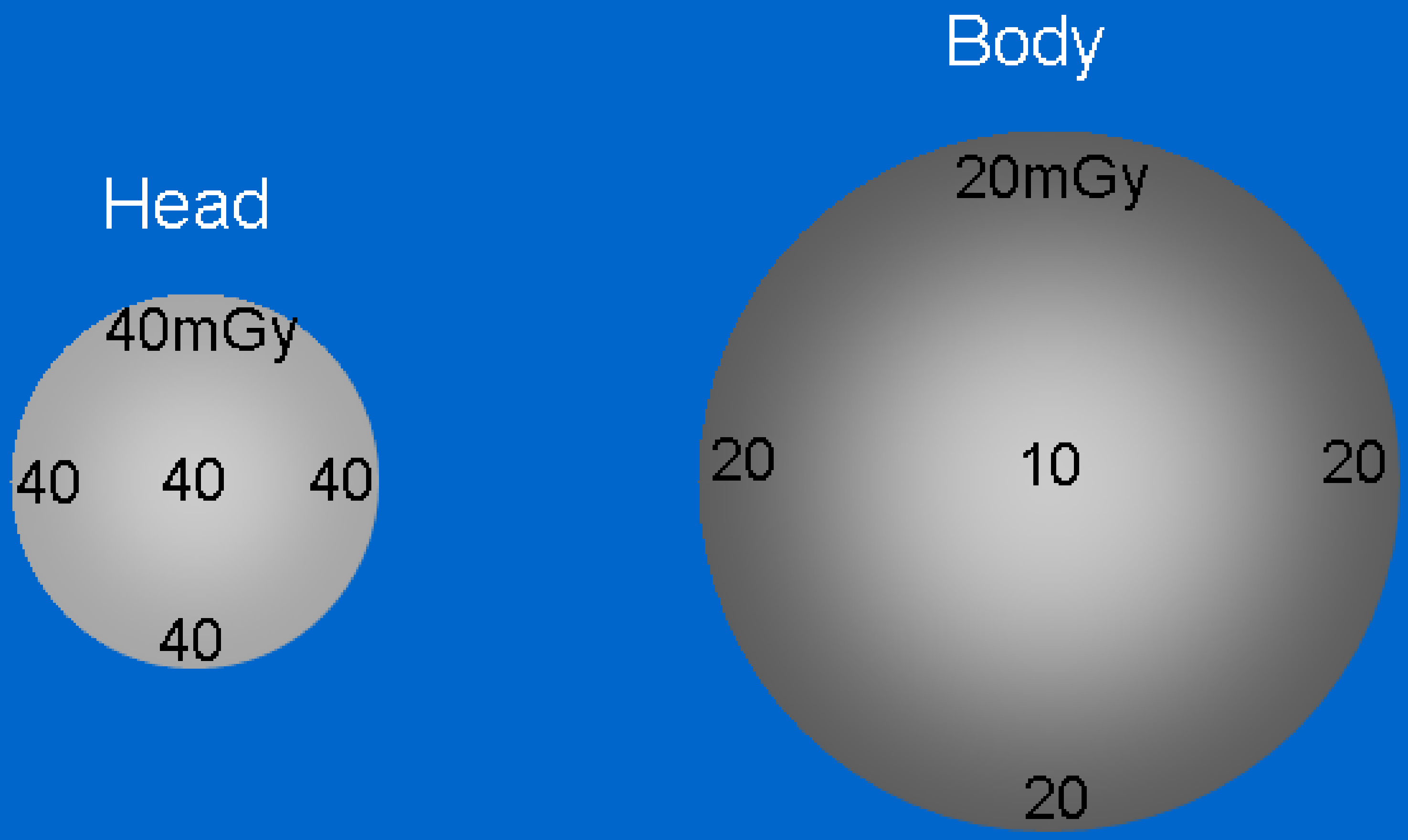
$CTDI_{100}$

- Standard Perspex phantoms
  - centre
  - periphery -1 cm depth (mean of 4 positions)



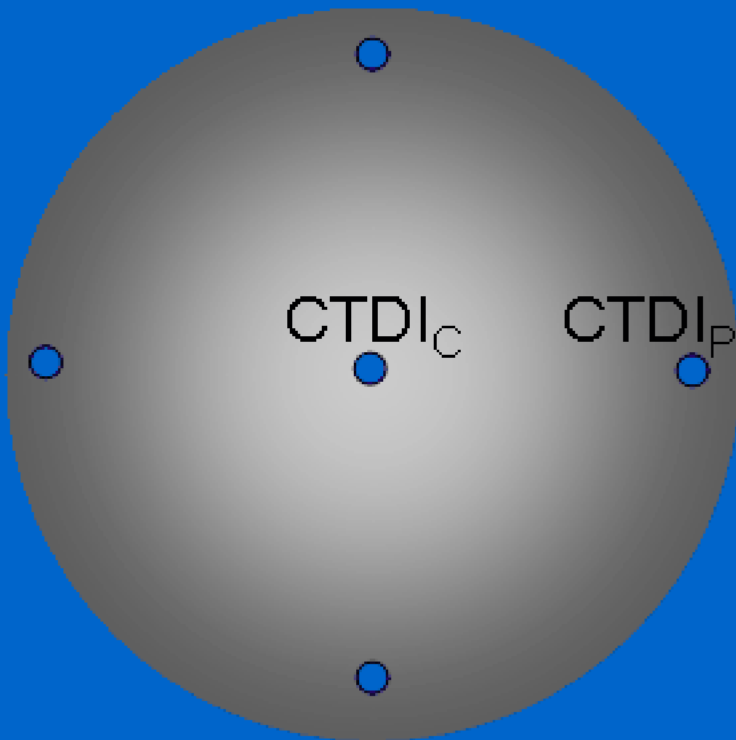
$CTDI_{100}$

- Typical $CTDI_{100}$ values



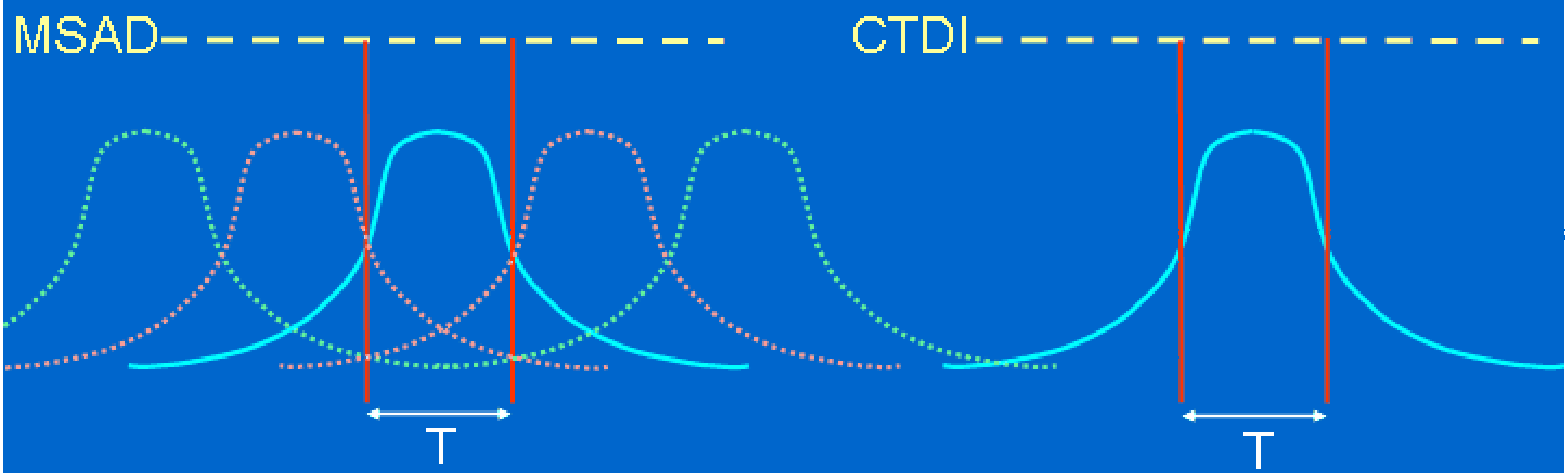
Average dose in scan plane: $CTDI_w$

- Weighted average CTDI represents the average dose in scan plane of Perspex phantom
- $CTDI_w = 1/3\ CTDI_{Centre} + 2/3\ CTDI_{Periphery}$



Average dose in scanned volume

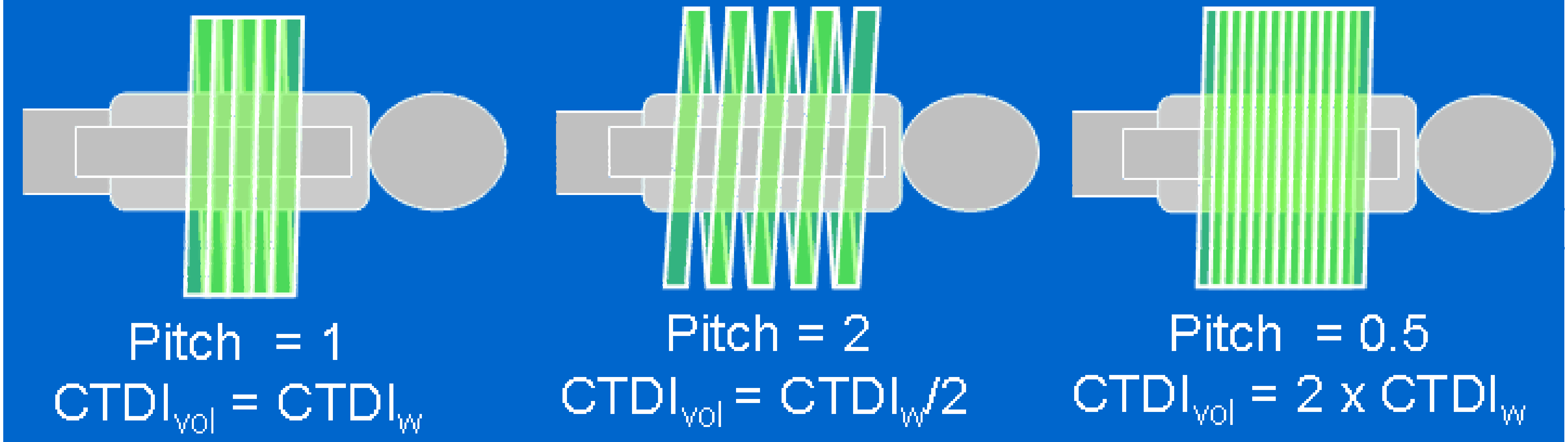
- $CTDI_w$ represents average dose in scanned volume if:
  - Couch translation/rotation = Nominal collimation
  - i.e. for Pitch = 1



- Need way of dealing with non-contiguous slices

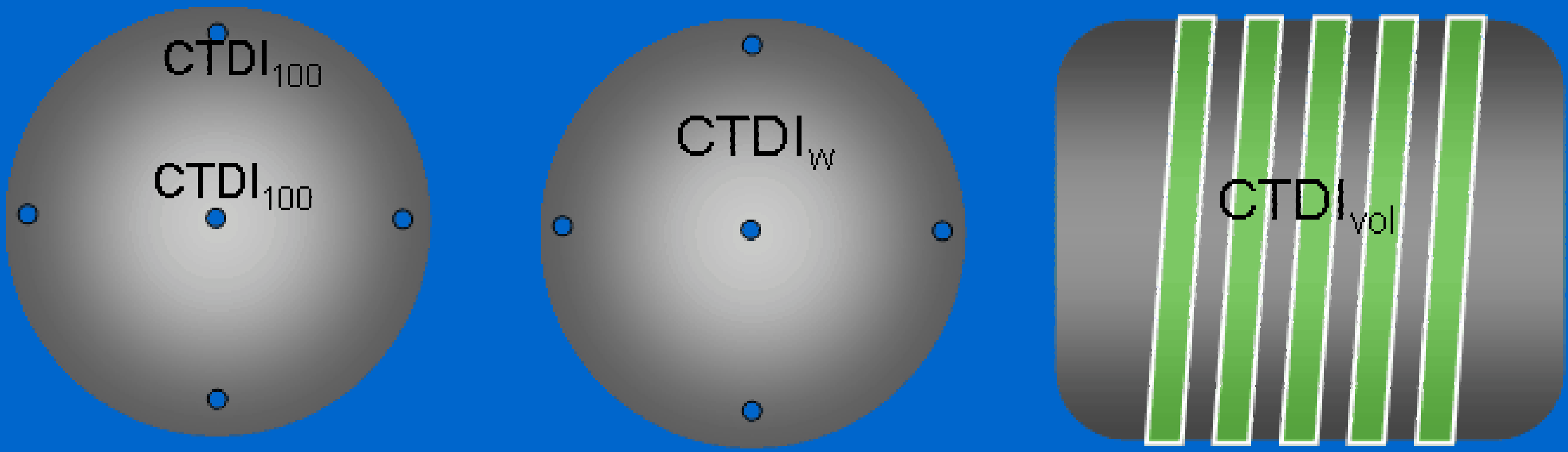
Average dose in scanned volume: $CTDI_{vol}$

- Volume CTDI takes account of non-contiguous exposure along z-axis
- $$CTDI_{vol} = \frac{CTDI_w}{Pitch}$$



CT absorbed dose summary

- $CTDI_{100}$: dose at a point in standard Perspex phantom
- $CTDI_{w}$: average in scan plane
- $CTDI_{vol}$: average dose over scanned volume



Normalised CTDI

$_nCTDI_{100}$

$_nCTDI_w$

$_nCTDI_{vol}$

} CTDI per mAs

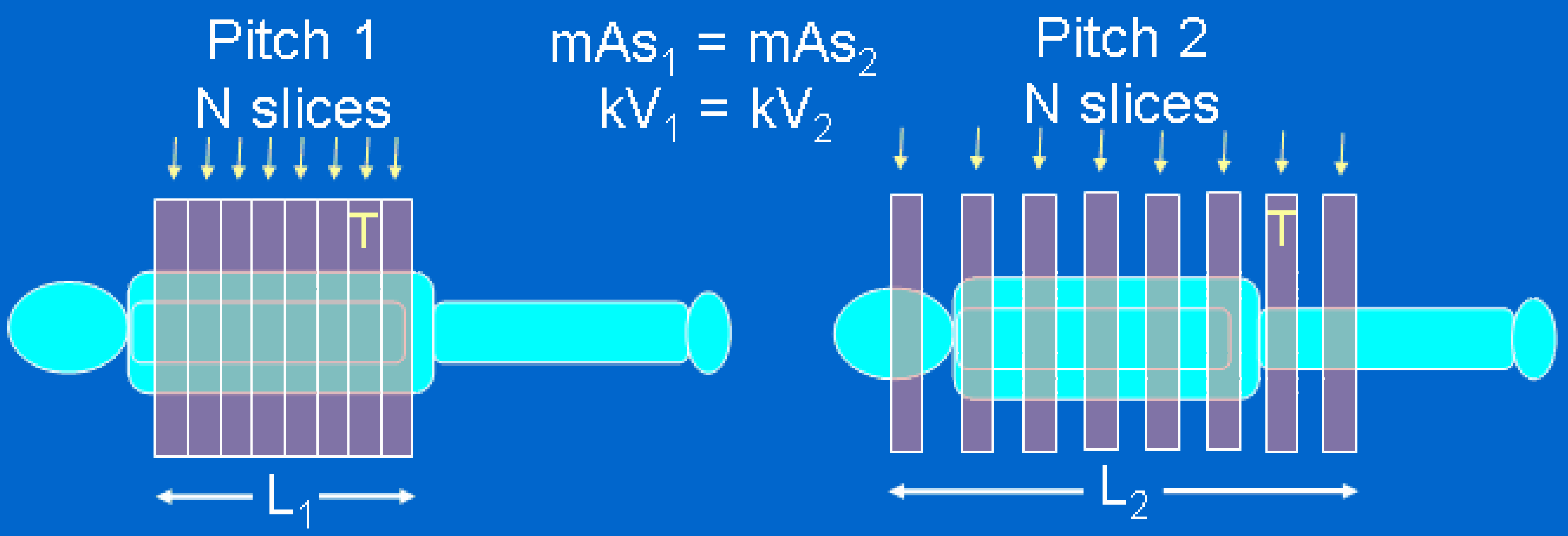
e.g. $CTDI_w$ = 20 mGy @ 200 mAs

$_nCTDI_w$ = 0.1 mGy

Dose length product

$$DLP = CTDI_{vol} \cdot L \text{ (mGy.cm)}$$

where L = scan length

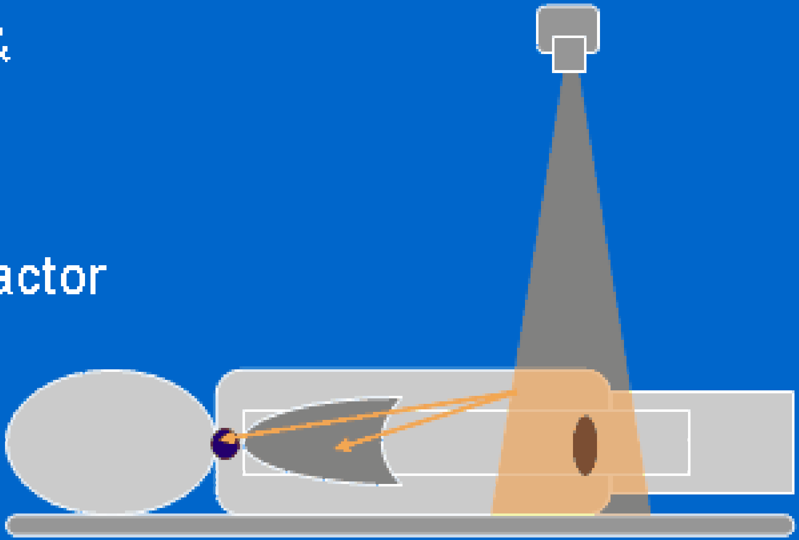


$$DLP_1 = DLP_2$$

as $CTDI_{vol2} = \frac{CTDI_{vol1}}{2}$

Effective Dose (E)

Need to know average dose to each organ & organ sensitivity :



1 → Calculate equivalent organ doses (H_T)

H_T = Absorbed organ dose x Quality Factor

2 → Apply organ sensitivity weighting factors (W_T) to doses

W_T from ICRP 60 → $W_T \times H_T$

3 → Effective Dose = sum of all organ doses x weighting factors

$$E = \sum W_T \times H_T$$

Estimates of Effective Dose

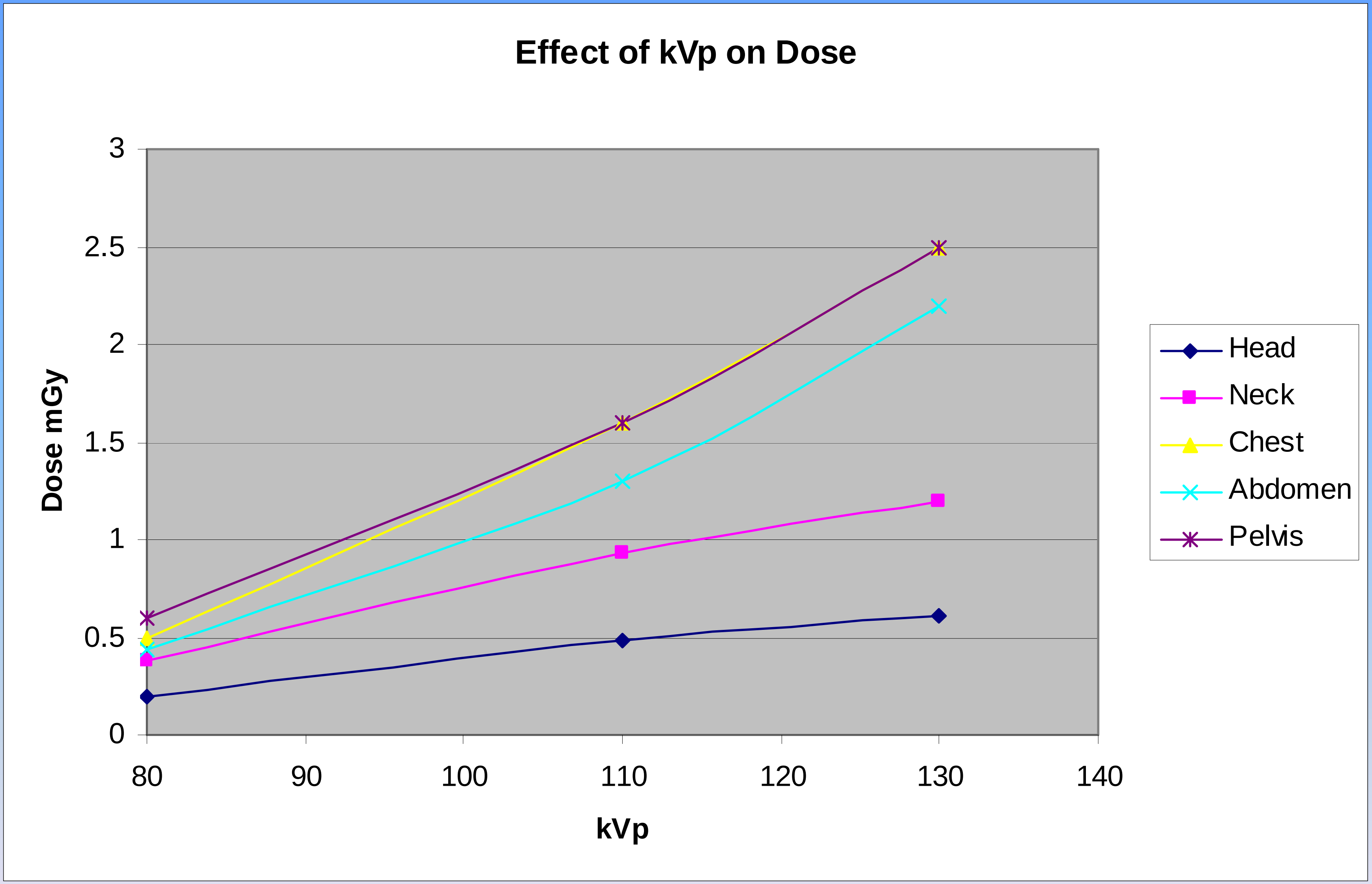
- Effective dose = DLP. CF (mSv)

Region of body	Conversion factor, EDLP ($mSv\ mGy^{-1}\ cm^{-1}$)
Head	0.0023
Neck	0.0054
Chest	0.017
Abdomen	0.015
Pelvis	0.019

Ref. European Guidelines on Quality Criteria for Computed Tomography, EUR 16262, May 1999

Dose Management - Factors under our Control

- Techniques Available
  - Automatic Tube Current Modulation – 20-60%
  - Weight based exposure settings
  - kVp reduction 80 – 100 kVp suitable for paediatric cases
  - Noise – just how much is acceptable for scan purpose
  - Scan Volume selection



Data based on 50mAs 5mm slices for a Siemens Emotion Duo Scanner

Patient dose increases with kVp if other factors kept constant

Effect of scan parameters on $CTDI_{vol}$

- Variation of dose with kV

kV	Relative $CTDI_{vol}$
140	1.4
120	1.0
80	0.4

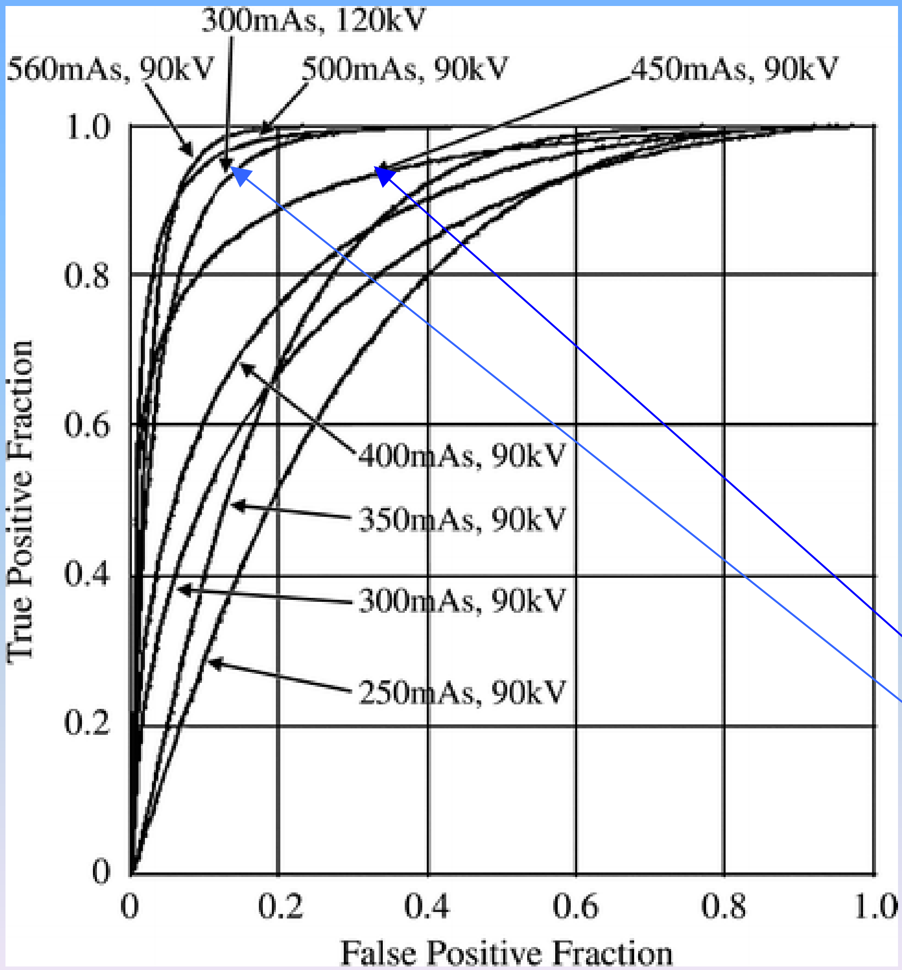
kV	Relative dose (for same noise)	
	Head	Body
130	1.0	1.0
110	1.2	1.1
80	1.6	2.6

Siemens Emotion 6 - ImPACT data

Who wins the Dose v Noise Argument?

- In general the higher kVp will reduce dose for the same noise level in the image .. however soft tissue contrast will be degraded.
- For the same level of noise in phantom images relative to a 28cm adult phantom it was found that mAs values can be reduced by factors of 0.56 for 25cm, 0.2 for 20cm and .054 for 15cm phantoms resulting in dose reductions of 36%, 71% and 91% respectively.
- Answer
  - If we do not adjust our exposure settings for different patient sizes we are not properly “managing” our dose either due to patient overexposure or producing noisy images.
  - However, it is more likely that higher patient doses will occur than will producing unacceptably noisy images.

Need to use ROC Studies to optimise



Radiation Dose Reduction without Degradation of Low-Contrast Detectability at Abdominal Multisection CT with a Low–Tube Voltage Technique: Phantom Study

Yoshinori Funama, PhD et al - Radiology

Represents dose saving of 35%
Using 90kVp 450 mAs

Effect of Scanner Selection

- Chest Scan 50 mAs 1sec 4 - 5mm slices
  - Emotion Duo 130 kVp 2.5
  - Sensation 64 140 kVp 2.2
  - Brilliance 140 kVp 2.7
  - Lightspeed 140 kVp 2.3
  - Acquillion 16 135 kVp 3.5

Why should scanner selection effect dose?

Factors include Gantry design (Focus to Skin Distance), Beam collimation, Penumbra, kVp and Beam Filtration

Pitch, Feed/Rotation

- Feed/rotation is the distance table moved per rotation (mm/rotation)
- Pitch or pitch factor is distance table moved per slice thickness.
- Slice collimation is total beam thickness = number of slices x detector channel width.
- For a feed/rotation of 15mm with a 8x1.25mm collimated beam, the pitch will be:-
  - 15mm/10mm = 1.5
- Dose calculation software generally requires a value for pitch, but scanner states feed/rotation.

Effect of Pitch and Slice Width

- $CTDI_{vol}$ and thus effective dose are inversely proportional to the pitch.
- Pitch values > 1 thus always reduce patient dose.
- Pitch values < 1 thus always increase patient dose.
- Slice width is the thickness of reconstructed slices and has no influence on patient dose …… except that if you want reconstructed slices of 3mm, you will need to use a collimated beam of 3mm increments or less.

Effect of Body Size

	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

The range represents minimum and maximum differences for a representative selection of scanners

If you use the same scan parameters for all patients, paediatric doses will be approximately double that of adults, and the risk factors higher still.

Effect of Body Region Scanned - Head

ImPACT CT Patient Dosimetry Calculator
Version 0.99x 20/01/06

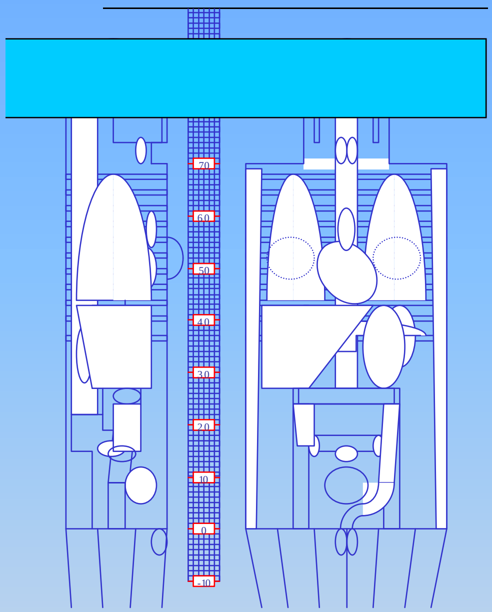
Scanner Model:			
Manufacturer:	Siemens		
Scanner:	Siemens Emotion Duo		
kV:	110		
Scan Region:	Head		
Data Set	MCSET17	Update Data Set	
Current Data	MCSET17		
Scan range			
Start Position	79	cm	Get From Phantom Diagram
End Position	94	cm	
Patient Sex:	f		

Acquisition Parameters:			
Tube current		100	mA
Rotation time		1	s
mAs / Rotation		100	mAs
Collimation		10	mm
Slice Width		5	mm
Pitch		1.2	
Rel. CTDI	Look up	1.00	at selected collimatic
CTDI (air)	Look up	21.0	mGy/100mAs
CTDI (soft tissue)		22.5	mGy/100mAs
${}_nCTDI_w$	Look up	14.5	mGy/100mAs

Organ	w_T	H_T	$w_T.H_T$
Gonads	0.2	0	0
Bone Marrow (red)	0.12	0.7	0.084
Colon	0.12	0.00013	0.000015
Lung	0.12	0.026	0.0031
Stomach	0.12	0.0012	0.00014
Bladder	0.05	7.3E-07	3.7E-08
Breast	0.05	0.0078	0.00039
Liver	0.05	0.0017	0.000085
Oesophagus (Thymus)	0.05	0.017	0.00085
Thyroid	0.05	0.56	0.028
Skin	0.01	0.76	0.0076
Bone Surface	0.01	3	0.03
Brain	0.025	10	0.25
Remainder 2	0.025	0.26	0.0064
Total Effective Dose (mSv)			**0.41**

Remainder Organs	H_T
Adrenals	0.00075
Brain	10
Upper Large Intestine	0.00012
Small Intestine	0.000091
Kidney	0.0006
Pancreas	0.0013
Spleen	0.002
Thymus	0.017
Uterus	0.000034
Muscle	0.27

$CTDI_w$ (mGy)	14.5
$CDTI_{vol}$ (mGy)	12.1
DLP (mGy.cm)	182



All scan conditions the same except for location

Effect of Body Region Scanned - Chest

ImPACT CT Patient Dosimetry Calculator
Version 0.99x 20/01/06

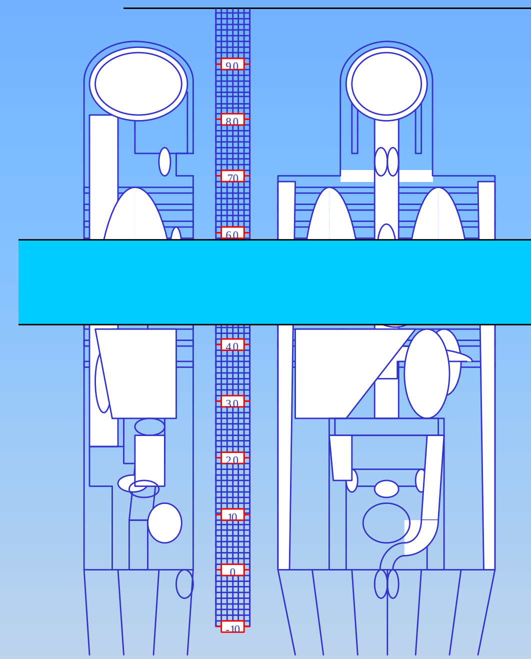
Scanner Model:			
Manufacturer:	Siemens		
Scanner:	Siemens Emotion Duo		
kV:	110		
Scan Region:	Body		
Data Set	MCSET20	Update Data Set	
Current Data	MCSET20		
Scan range			
Start Position	44	cm	Get From Phantom Diagram
End Position	59.5	cm	
Patient Sex:	f		

Acquisition Parameters:			
Tube current		100	mA
Rotation time		1	s
mAs / Rotation		100	mAs
Collimation			mm
Slice Width			mm
Pitch		1.2	
Rel. CTDI	Look up	1.00	(assumed)
CTDI (air)	Look up	21.0	mGy/100mAs
CTDI (soft tissue)		22.5	mGy/100mAs
$_nCTDI_w$	Look up	6.5	mGy/100mAs

Organ	w_T	H_T	$w_T.H_T$
Gonads	0.2	0.0089	0.0018
Bone Marrow (red)	0.12	1.2	0.15
Colon	0.12	0.0072	0.00087
Lung	0.12	6.3	0.75
Stomach	0.12	0.58	0.069
Bladder	0.05	0.0019	0.000096
Breast	0.05	6.3	0.31
Liver	0.05	0.87	0.044
Oesophagus (Thymus)	0.05	7.9	0.4
Thyroid	0.05	0.17	0.0087
Skin	0.01	0.9	0.009
Bone Surface	0.01	2.6	0.026
Thymus	0.025	7.9	0.2
Remainder 2	0.025	0.8	0.02
Total Effective Dose (mSv)			**2**

Remainder Organs	H_T
Adrenals	1.1
Brain	0.0077
Upper Large Intestine	0.045
Small Intestine	0.032
Kidney	0.21
Pancreas	0.86
Spleen	0.64
Thymus	7.9
Uterus	0.0067
Muscle	0.87

$CTDI_w$ (mGy)	6.5
$CDTI_{vol}$ (mGy)	5.5
DLP (mGy.cm)	85



All scan conditions the same except for location

Effect of Body Region Scanned - Pelvis

ImPACT CT Patient Dosimetry Calculator

Version 0.99x 20/01/06

Scanner Model:		
Manufacturer:	Siemens	
Scanner:	Siemens Emotion Duo	
kV:	110	
Scan Region:	Body	
Data Set	MCSET20	Update Data Set
Current Data	MCSET20	

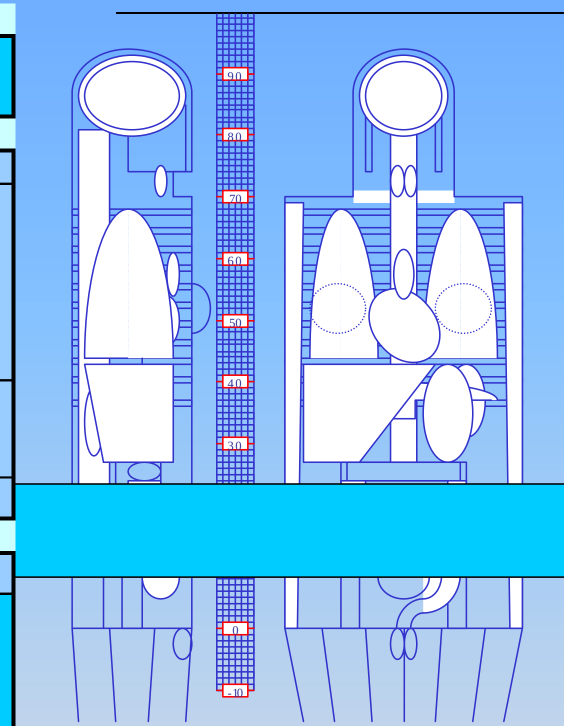
Scan range			
Start Position	4	cm	Get From Phantom Diagram
End Position	19.5	cm	
Patient Sex:	f		

Acquisition Parameters:			
Tube current		100	mA
Rotation time		1	s
mAs / Rotation		100	mAs
Collimation			mm
Slice Width			mm
Pitch		1.2	
Rel. CTDI	Look up	1.00	(assumed)
CTDI (air)	Look up	21.0	mGy/100mAs
CTDI (soft tissue)		22.5	mGy/100mAs
$_{n}CTDI_{w}$	Look up	6.5	mGy/100mAs

Organ	w_T	H_T	$w_T.H_T$
Gonads	0.2	5.8	1.2
Bone Marrow (red)	0.12	1.3	0.16
Colon	0.12	4.1	0.49
Lung	0.12	0.0053	0.00063
Stomach	0.12	0.13	0.015
Bladder	0.05	7.4	0.37
Breast	0.05	0.0046	0.00023
Liver	0.05	0.075	0.0038
Oesophagus (Thymus)	0.05	0.001	0.00005
Thyroid	0.05	0.0014	0.000071
Skin	0.01	0.87	0.0087
Bone Surface	0.01	1.5	0.015
Remainder 1	0.025	1.3	0.032
Remainder 2	0.025	1.3	0.032
Total Effective Dose (mSv)			**2.3**

Remainder Organs	H_T
Adrenals	0.029
Brain	0
Upper Large Intestine	2.1
Small Intestine	2.5
Kidney	0.14
Pancreas	0.073
Spleen	0.059
Thymus	0.001
Uterus	6.5
Muscle	1.3

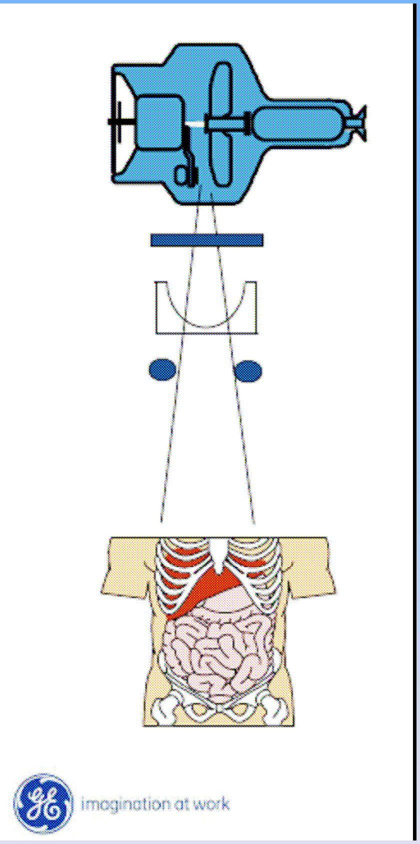
$CTDI_w$ (mGy)	6.5
$CDTI_{vol}$ (mGy)	5.5
DLP (mGy.cm)	85



All scan conditions the same except for location

Effect of Patient Position in Scanner

- If centre of patient is not aligned with the centre of the CT beam, then bowtie filters used for dose reduction can lead to underdosing central tissues and overdosing of peripheral tissues such as the breast.
- This leads to both loss of image quality in centre of body as well as potential increase in dose to peripheral tissues.



Use of Tube Current Modulation

- Manufacturers now employ CT tube current modulation to either reduce dose or maintain image quality (optimize noise levels).
- These typically reduce the tube current whilst scanning through thin sections of the body, or set tube current based on a value such as patient width.
- Choosing a inappropriate value can however lead to an increase in patient dose so care is required in selecting values used.

Adjusting mAs for patient size

- Automatic tube current control (mA modulation)
- Manufacturers' weight / age based pre-programmed paediatric protocols
- mAs adjusted for lateral patient dimensions

CH McCollough, Dose optimization in CT: implementation and clinical acceptance of size-based technique charts, RSNA 2002

Patient Width*(cm)	Relative mAs
> 21 – 26	0.4
> 26 – 31	0.5
> 31 – 36	0.7
> 36 – 41	1.0
> 41 – 46	1.4
> 46 – 51	2.0

* Lateral patient width based on A-P scout at level of liver

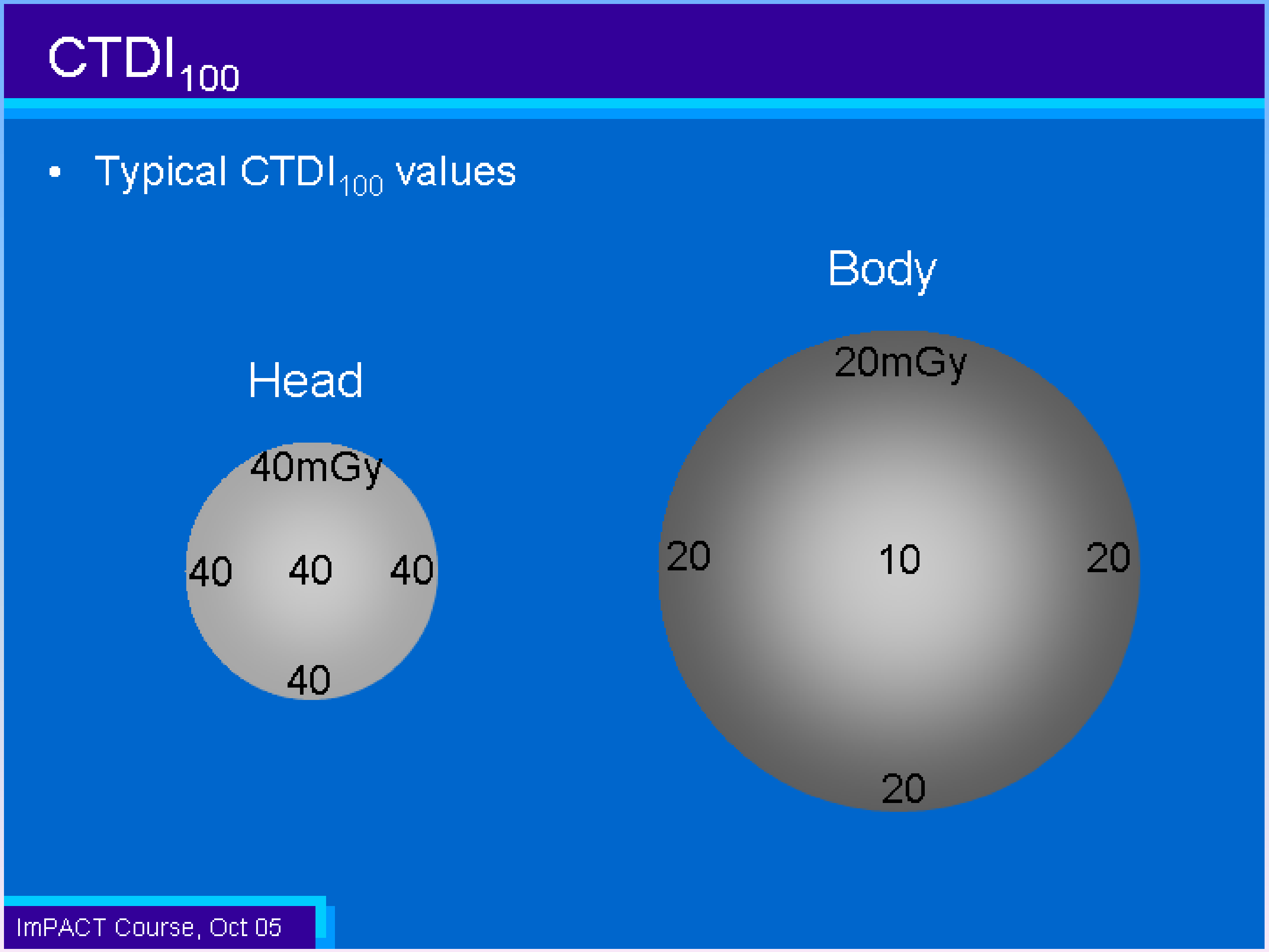
Avoidance of Exposure of Sensitive Tissues

- It is common practice to angulate the gantry to minimise eye exposures in conventional CT – not possible with the fixed gantry in hybrid scanners – however lower dose procedure would not approach threshold for eye damage.
- Risk factors are also dependant on patient age volume to be scanned, and should be as part of the decision making process as to whether CT component will benefit the patient.

Some dosimetry traps for Young Players

- The CTDI error
  - CT console displays a value different from expected.
- 50 mA 1 sec 5mm weighted ${}_{n}CTDI_{w}$ = 1.5
- Expected value <1
- Change console from Head to Body region and displayed value changes to 0.6

$CTDI_v$ values for head and body use measured $CTDI_{100}$ data for 16cm and 32cm phantoms respectively – you need to correctly identify body part to get correct dosimetry



Some dosimetry traps for Young Players

- When using tube current modulation, the set mA/mAs designates the **nominal** or **reference** tube current for the scan only – what is the actual mA for the scan?
- Following the scan procedure a value of the **effective** mAs is typically displayed.
- When using CT dose calculators such as that produced by the ImpaCT group, they typically need the user to input a value for the mA and an average value needs to be provided.
- Refer to the manufacturer's documentation. For a Siemens CT the average mA is calculated from the expression:
  - Effective mAs = (Average mA * rotation time)/pitch
  - Average mA = rotation time / (pitch * Effective mAs)

Some dosimetry traps for Young Players

- **Measured $CTDI_{100}$ value appears very low!**
- When measuring $CTDI_{100}$ using a 100 mm pencil chamber one must remember that $CTDI_{100}$ is defined as Absorbed Dose/ Nominal Slice Width.
- Thus for a CTDI chamber reading of 1.56 mGy (corrected for T & P etc) with a slice width of 10mm, the nominal slice width is 100mm/10mm = 0.1 of the chamber length and the value for $CTDI_{100}$ is thus 1.56mGy/0.1 or 15.6 mGy

Practical CT dose reduction

- Best techniques are the easiest ones:-
  - If the CT does not assist in the diagnosis – do not do it.
  - Only scan the minimum volume necessary
  - Lower kVps can give lower doses for smaller body sections - for the same image quality
  - mAs are like MBqs – only use as many as needed.
  - The coarser the pitch – the lower the dose

Can we reduce effective dose through shielding?

- **Yes**
  - A number of studies have been undertaken that have shown dose reductions of up to 50% for breast tissue shielded by bismuth or lead, without unacceptable artefacts. Other researchers are reporting dose reductions up to 73% for tungsten-antimony alloy shields that are draped over the patient during scanning.
- The problem with their use in PET/CT and SPECT/CT is the transmission artefacts they would produce if used during the SPECT/PET part of the study.

Other CT dose reduction strategies

- Scanning patients prone rather than supine.
  - This makes uses of the dose reduction produced by the bed material – can be around 15%.
  - Problem is that the longer time period required for nuclear medicine studies and level of discomfort would be both unacceptable for the patient and increase the probability of patient movement.

What we are fighting against!!

- At a recent installation after setting up workflows for low dose CT scanning, the following comment was made by the supplier's applications trainer:-
  - "Just don't tell anyone it's our CT Scanner"
- Such comments reinforce the general, and **incorrect**, perception that for an image to be "good" it must "look good".

Which is the optimal imaging situation ?

- ✓ good

  I get all the information needed to treat the patient and I like this examination

- ✓ acceptable

  I get all the information needed to treat the patient but I don't like very much this examination

- ✓ unacceptable

  I don't get all the information needed to treat the patient and I don't like this examination at all

Summary

- Our objective in imaging is the appropriate **management** of dose.
- The required information must be available for the diagnostic objective of a procedure.
- The procedure for selecting exposure parameters should be appropriate for the study and dose, but not overly complex to risk errors requiring repeats or loss of usable data.
- We should be reviewing our exposures over time to validate whether the requirements for image quality and patient dose are being properly managed.

Summary (cont)

- Remember – the dosimetry data we use for both the nuclear medicine scans and the CT scans is only representative of what a standard phantom will receive.
- The associated risk factors apply to population groups rather than individuals and must be used judiciously.

CT dose contribution to Nuclear Medicine

- For most procedures the use of low dose CT scanning (5mm slices with 50 mAs/slice) will result in effective doses ranging from less than 0.5 mSv for a head/neck region to around 3.5mSv for a whole body scan.
- Proper dose management techniques should be implemented to meet the objectives of the diagnostic procedure whilst minimising the radiation detriment to the patient.

Resource material

- St George's Hospital in London is a great resource for CT dosimetry information and I thank them for allowing the presenter the use of their material.
- The content of their training courses, CT dose calculator and other invaluable material is available on the ImpACT website at:-
  - http://www.impactscan.org/index.htm