Patients are not made of plastic

Using Water-Equivalent Diameter to calculate patient size and Size-Specific Dose Estimates for CT Scans

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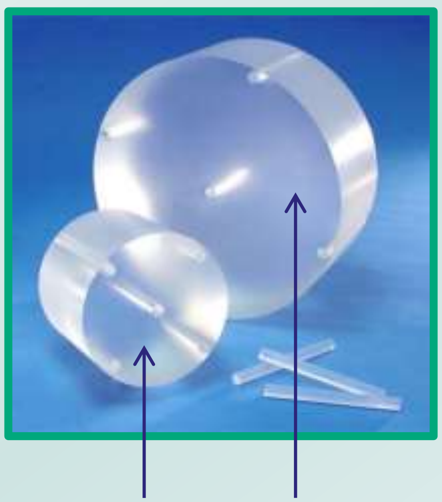
Dose Indices

$CTDI_{vol}$

- dose to air *measured using*
- 100mm pencil ionisation chamber *inside a*
- polymethyl methacrylate (PMMA) phantom



16cm (head) & 32cm (body) diameters

Patient Name: CTDI32_02 Exam no: 2738
Accession Number: 16 Jul 2018
Patient ID: MPQ160720180003 Discovery MI
Exam Description: Abdomen

Dose Report

Series	Type	Scan Range (mm)	CTDIvol (mGy)	DLP (mGy-cm)	Phantom cm
1	Scout	-	-	-	-
2	Axial	I60.000-I229.375	15.33	260.62	Body 32
2	Helical	I60.000-I229.375	18.66	348.47	Body 32
3	Axial	I60.000-I229.375	14.20	241.35	Body 32
			Total Exam DLP:	850.45	

1/1

$DLP = \text{scan length} \times CTDI_{vol}$

W: 1024 L: -512

Dose Indices

- What is the issue with the dose indices used?
  - PMMA phantom is homogeneous: patient is not
    - Bones, lungs (air), organs, fat
  - PMMA phantom is cylindrical: patient is not
    - Larger in one dimension than the other
  - PMMA phantom is plastic: patient is not
- Thus, $CTDI_{vol}$ is ***not*** a suitable descriptor for patient dose
- Patient size and/or composition should be taken into account: Size-Specific Dose Estimates

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Study Outline

- We want to know :
  - if taking patient size into account affects reported dose?
  - and, if so, by how much?
- Identified 823 suitable Abdomen-Pelvis CT exams from 01/11/17 to 24/04/18
- Calculated patient diameters and assigned size categories
- Obtained SSDEs and compared to reported dose for each category

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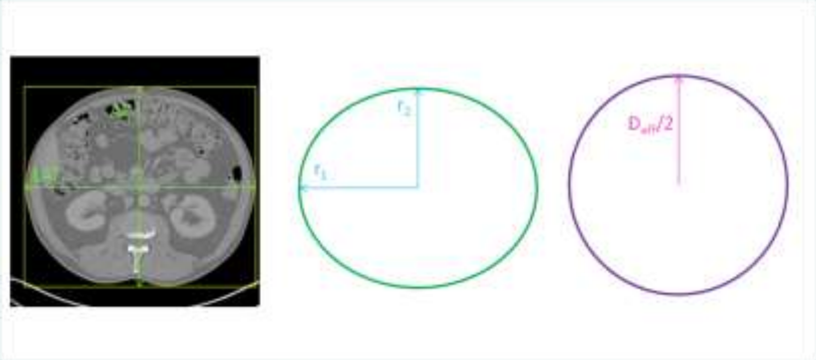
Estimating Patient Diameter

Effective Diameter

- Assume patient cross-section is elliptical
  - Lateral dimension (LAT) = $2*r_1$
  - Anterior-Posterior dimension (AP) = $2*r_2$
- Area of ellipse: $A = \pi r_1 r_2$
- Diameter of circle of same area: $D_{eff} = \sqrt{AP \times LAT}$



Estimating Patient Diameter

Water-Equivalent Diameter

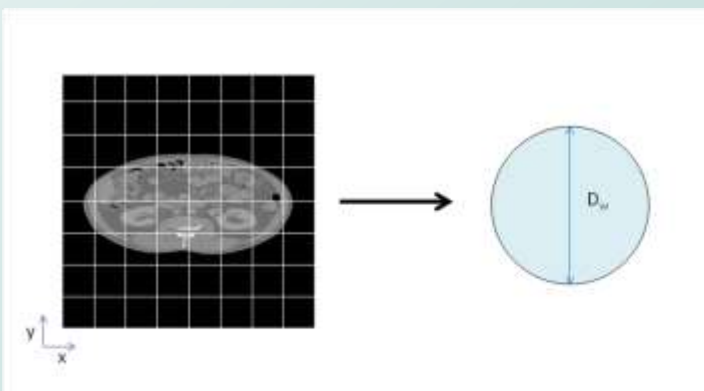
- The X-ray attenuation of a patient can be expressed in terms of a cylinder of water having the same attenuation
- CT number or attenuation value of pixel (x,y) in the CT image is defined using the linear attenuation coefficient of water
  - Measured in Hounsfield Units (HU)

$$\mathrm{CT}(x,y) = \left(\frac{\mu(x,y) - \mu_{water}}{\mu_{water}}\right) \times 1000$$

Estimating Patient Diameter

Water-Equivalent Diameter

- Calculate area of patient body and find mean CT number in this area to obtain water-equivalent diameter



$$D_w = 2\sqrt{\frac{A_w}{\pi}} = 2\sqrt{\left[\frac{1}{1000}\overline{\mathrm{CT}(x,y)}_{ROI} + 1\right]\frac{A_{ROI}}{\pi}}$$

Estimating Patient Diameter

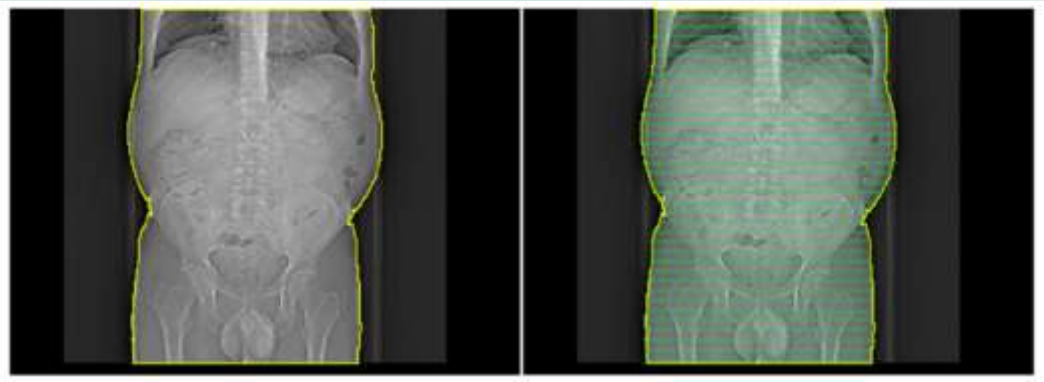
Water-Equivalent Diameter

- Takes attenuation of the body into account
- In general, expect water-equivalent diameter to be:
  – larger in areas with high attenuation (i.e. bone)
  – smaller in areas with low attenuation (i.e. lungs)

Estimating Patient Diameter

AP Localiser Scan

- Each pixel in a horizontal line is a ray-sum, L_w
  - The more attenuation, the higher the ray sum and the brighter the pixel
  - Adding the contributions from each pixel in a horizontal line gives water-equivalent area of that section



$$A_w = \sum L_w \times d$$

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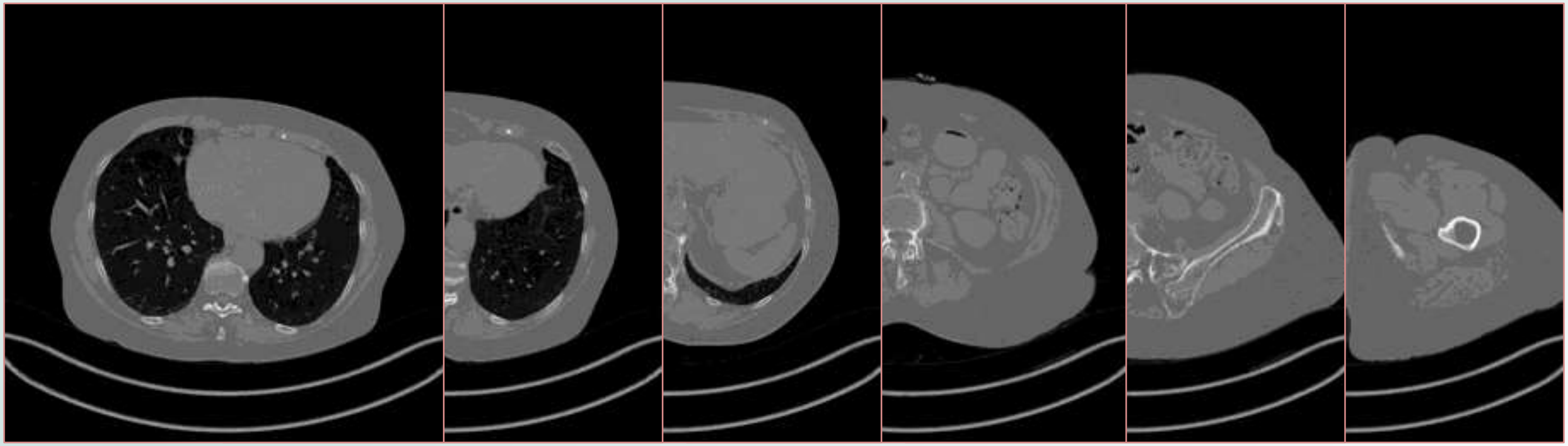
Calculating Diameter from CT Images

- ImageJ is an open source Java-based image processing package
  - Can handle 'stacks' of images sharing one window
  - Can identify pixels having a value over a certain threshold
  - Can define regions of interest
  - Can extract data: dimensions, area, mean pixel value
  - Can extract DICOM information

Calculating Diameter from CT Images

- Import CT image
- A CT image is a stack of images along the body of the patient

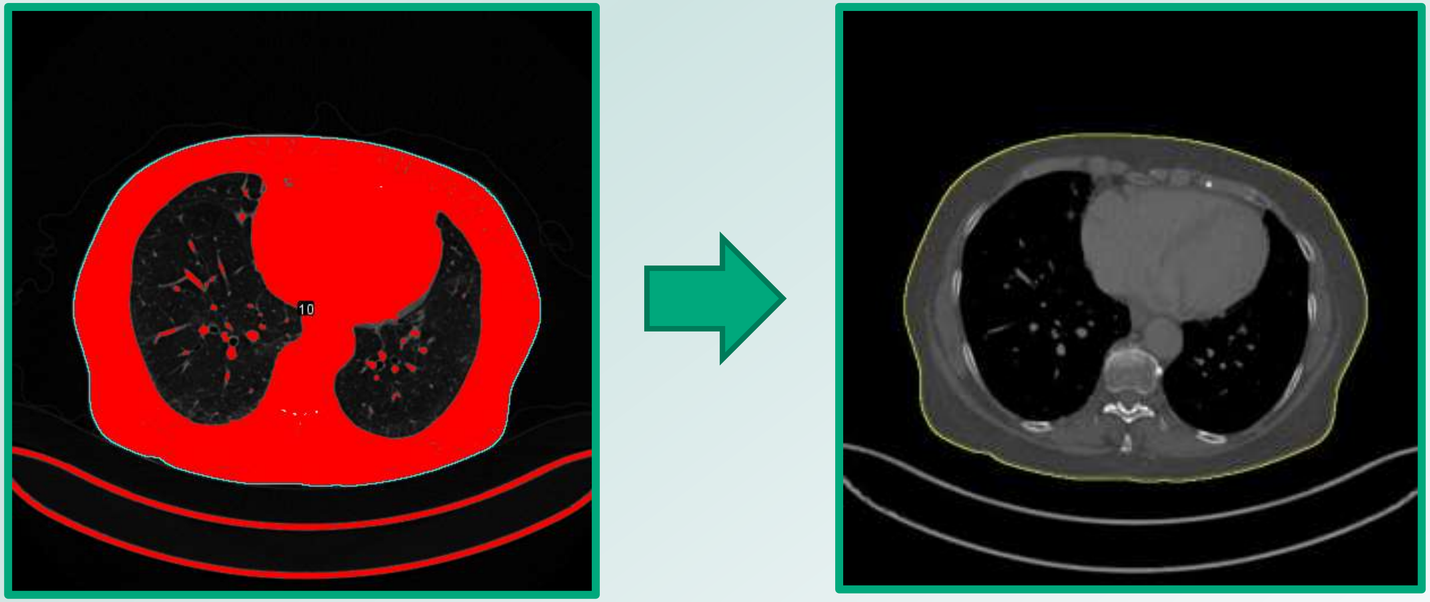


Calculating Diameter from CT Images

- Can identify pixels having a value over a certain threshold
  - Create a binary image by setting a threshold value of -140HU to isolate body

Calculating Diameter from CT Images

- Can define regions of interest (ROIs)
  - Outline only the body and copy this to the original image for each slice



Calculating Diameter from CT Images

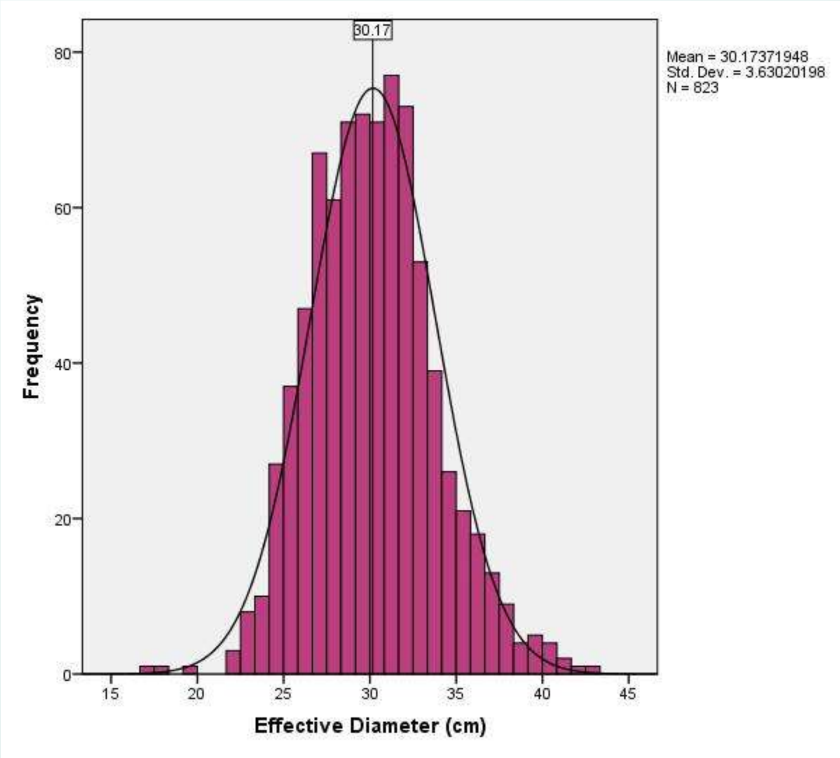
- Can extract data:
  - dimensions, area, mean pixel value

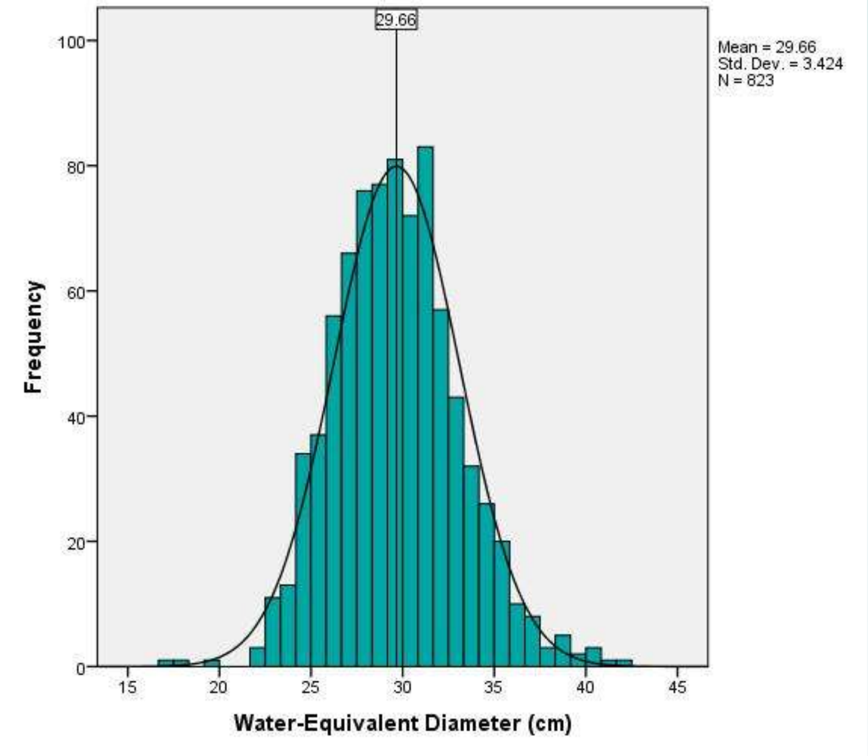
- Extract area of ROI
- Extract mean CT value within ROI
  - **water-equivalent diameter**

- Extract maximum x and y dimensions of ROI
  - **effective diameter**

Calculating Diameter from CT Images

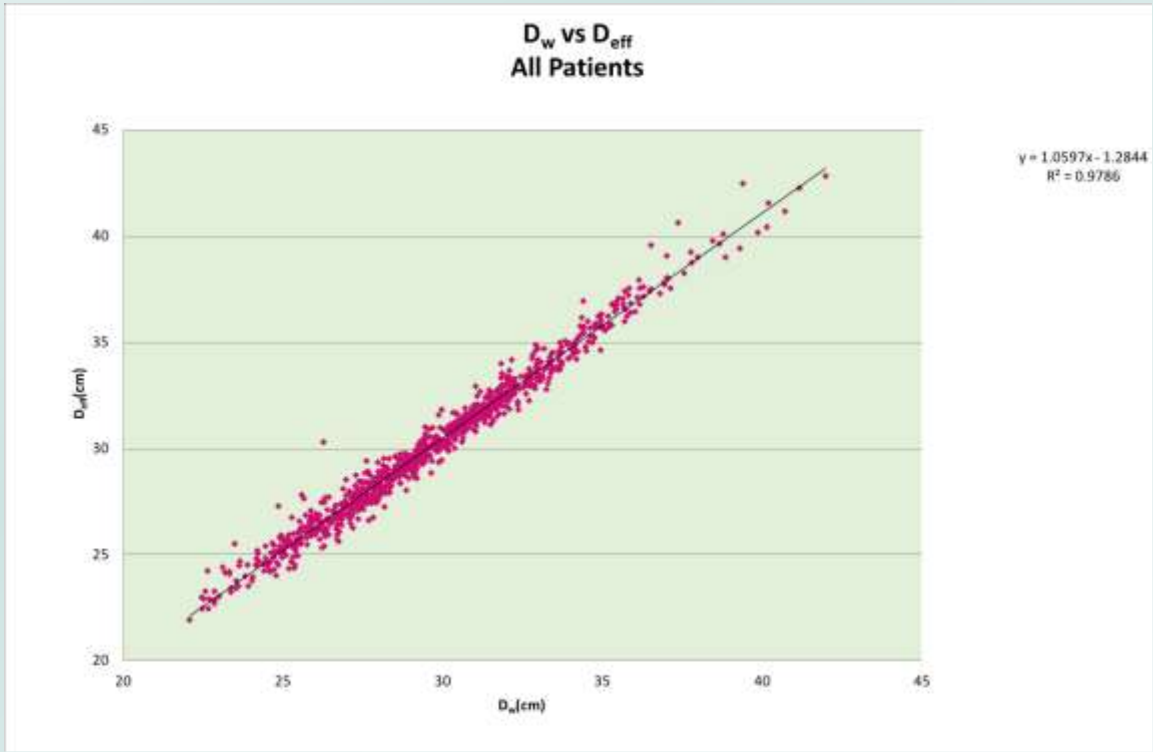
- Distributions of patient diameter were obtained





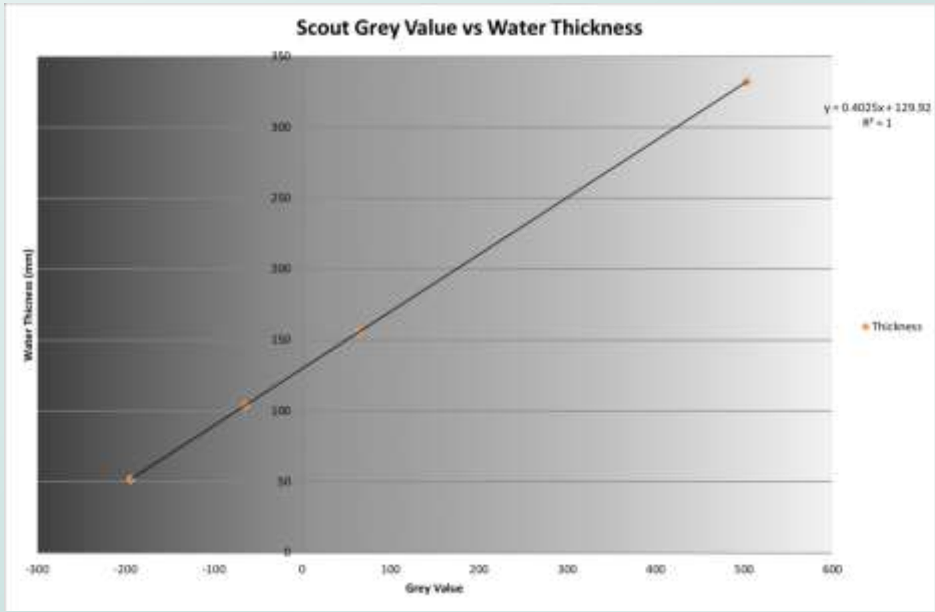
Calculating Diameter from CT Images

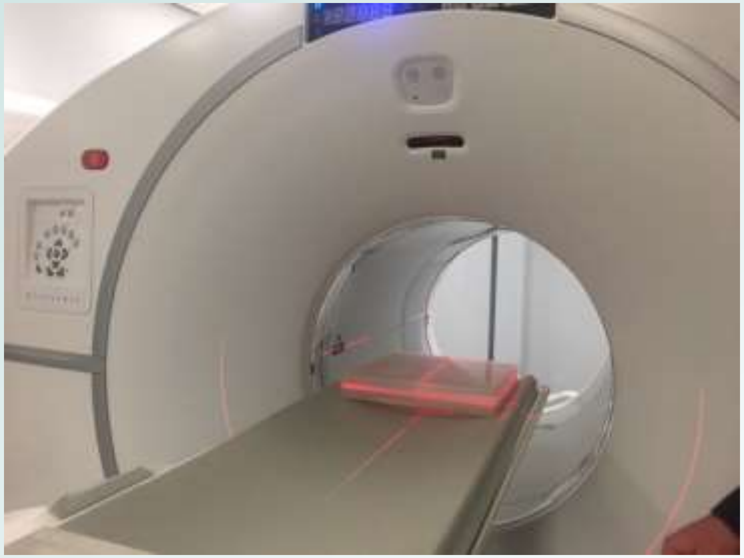
- Water-equivalent diameter and effective diameter were found to be interchangeable for abdomen-pelvis CT scans



Calculating Diameter from the SPR

- Experimental data used to calibrate grey value to water-thickness
  - Perspex blocks & CTDI phantoms
  - Offset due to couch

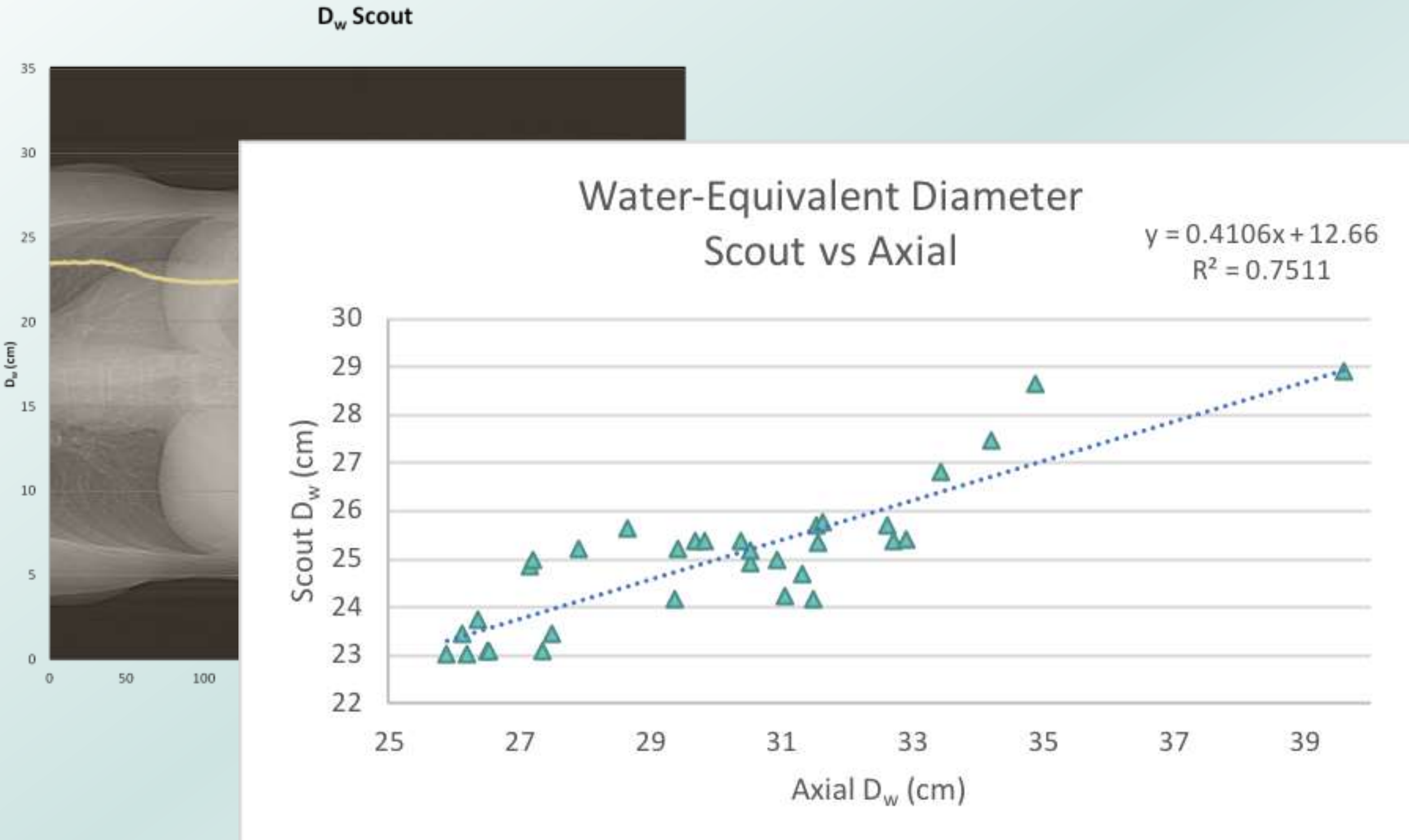




Calculating Diameter from the SPR

- ImageJ used to
  - identify patient contour
  - sum pixel values for each horizontal line
- Convert sum to water-thickness and take couch offset and detector spacing into account
- Calculate water-equivalent diameter for each horizontal line

Calculating Diameter from the SPR



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Size-Specific Dose Estimates

- The average diameter over all slices, *x*, is used to obtain a conversion factor:

$$y = ae^{-bx}$$

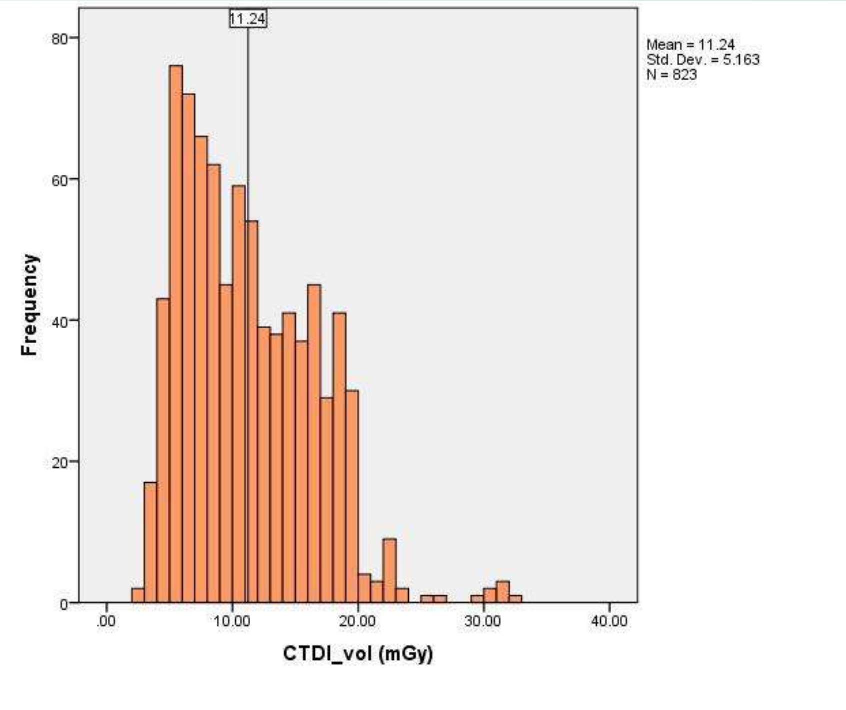
[AAPM TG 204]

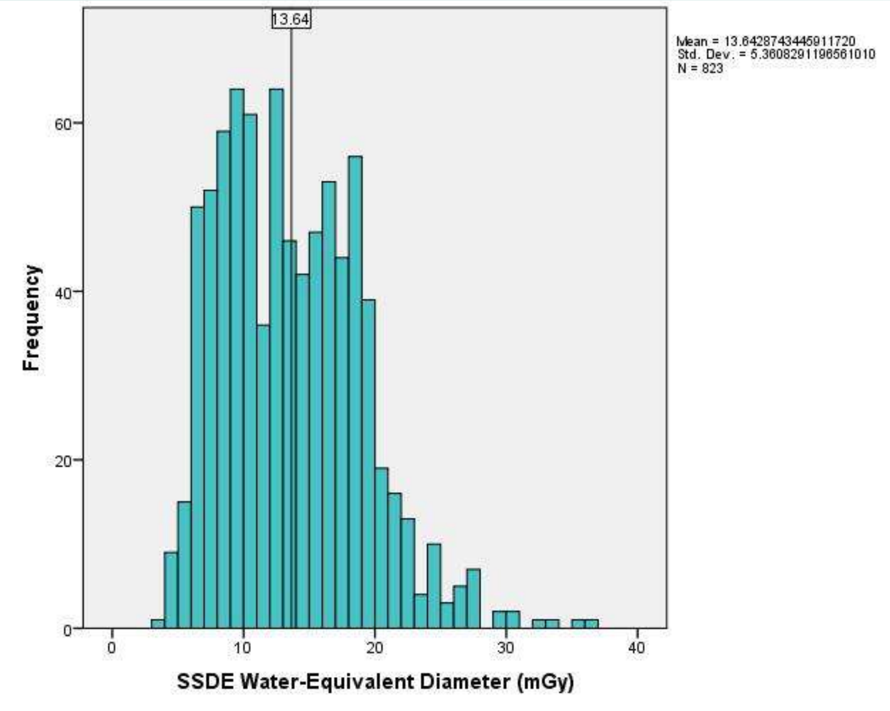
- This is then used to correct $CTDI_{vol}$ for patient size

$$\mathbf{SSDE = \mathit{y} \times CTDI_{vol}}$$

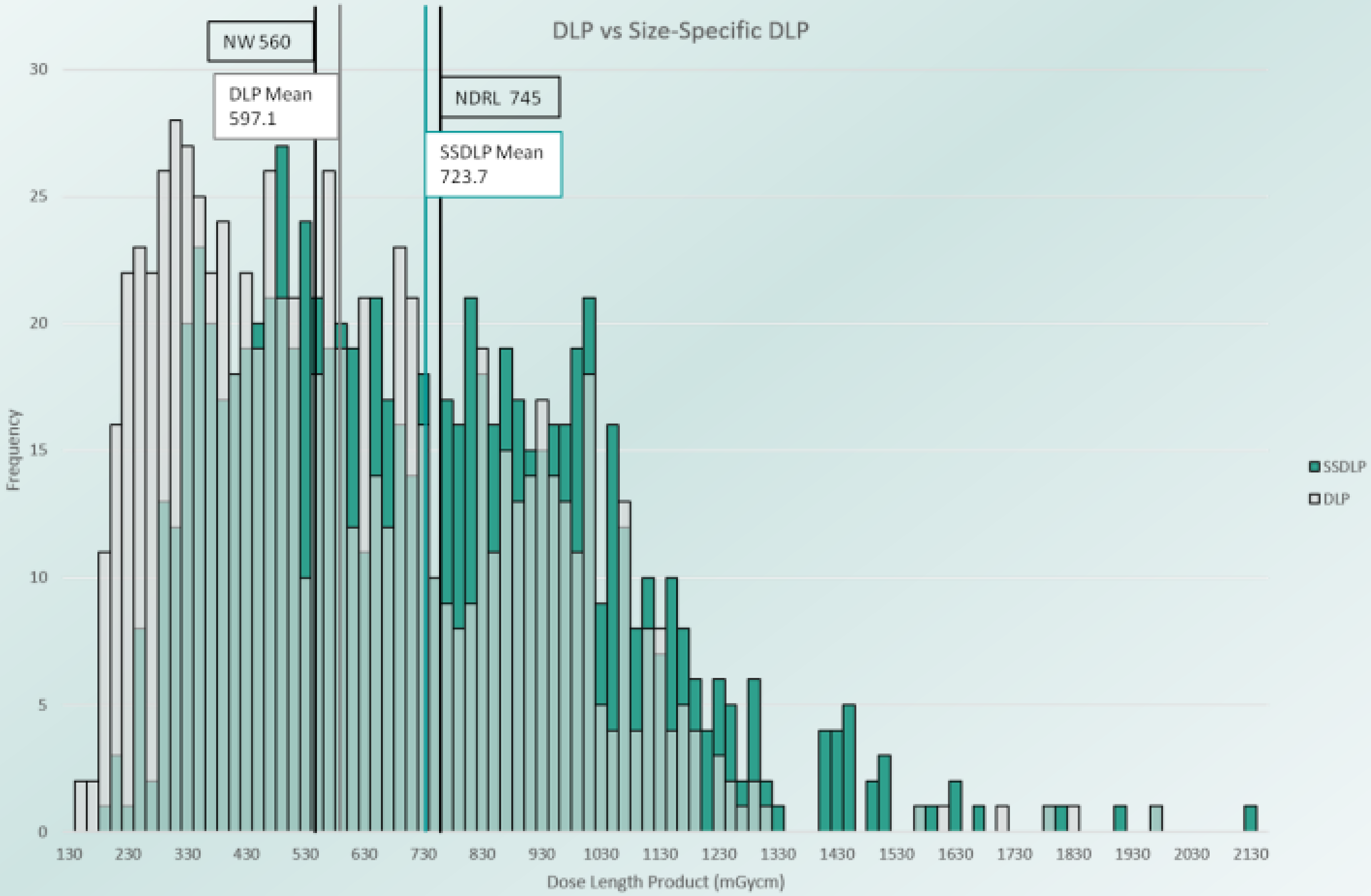
Size-Specific Dose Estimates

- $CTDI_{vol}$ misrepresents dose by ≈20%



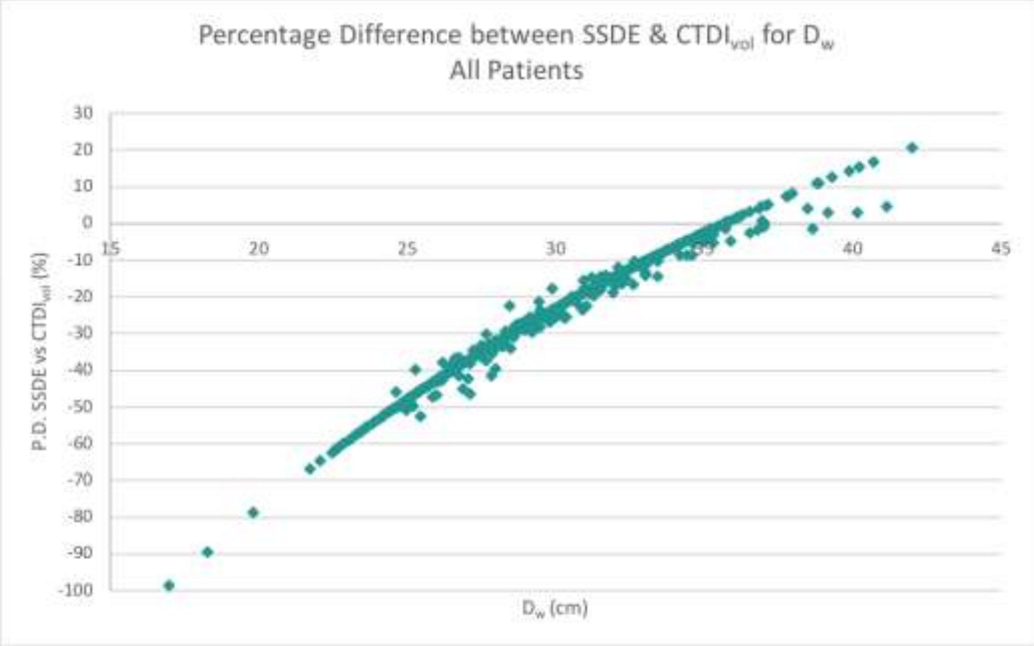


Size-Specific Dose Estimates



Size-Specific Dose Estimates

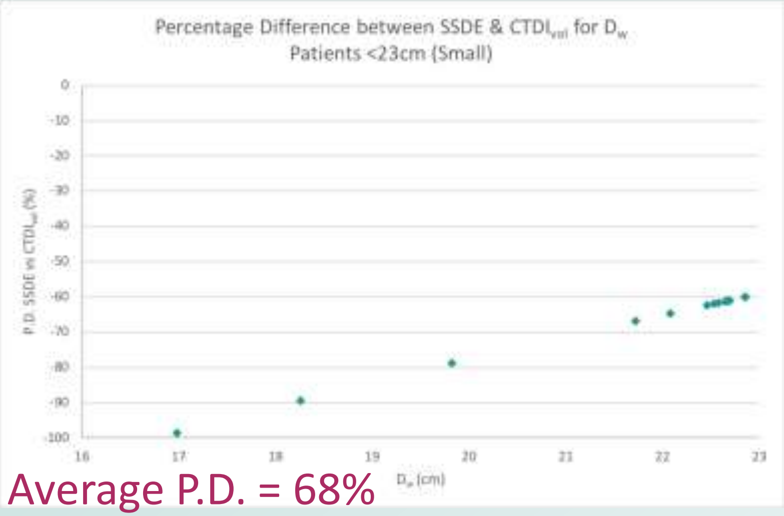
- Percentage difference (P.D.) between displayed $CTDI_{vol}$ and SSDE for D_w shows misrepresentation of dose is most extreme for patients of smaller diameters



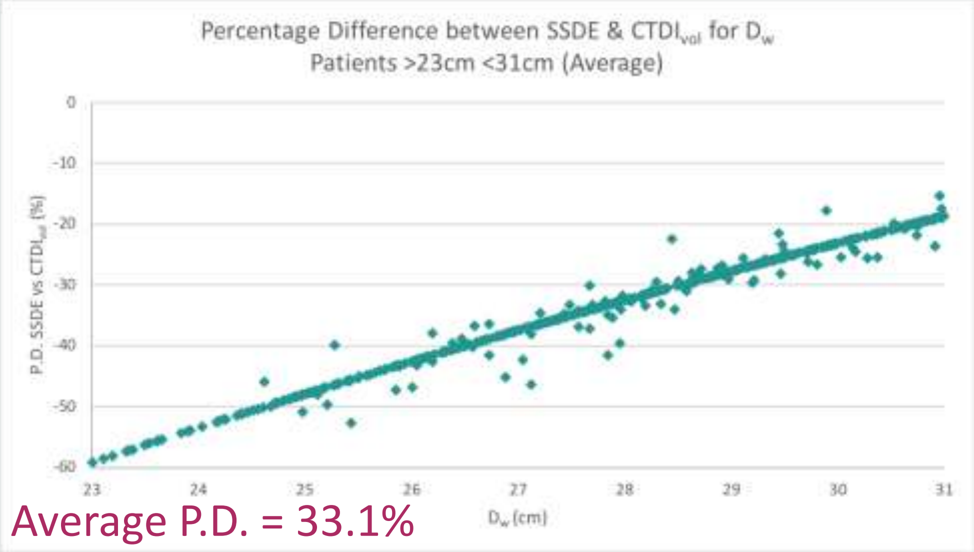
Size-Specific Dose Estimates

- Patient size categories

Category	D_w(cm)
Small	$D_w < 23$
Average	$23 \leq D_w < 31$
Large	$31 \leq D_w < 34$
Very Large	$D_w \geq 34$



Average P.D. = 68%



Average P.D. = 33.1%

Size-Specific Dose Estimates

- Patient size categories

Category	D_w(cm)
Small	$D_w < 23$
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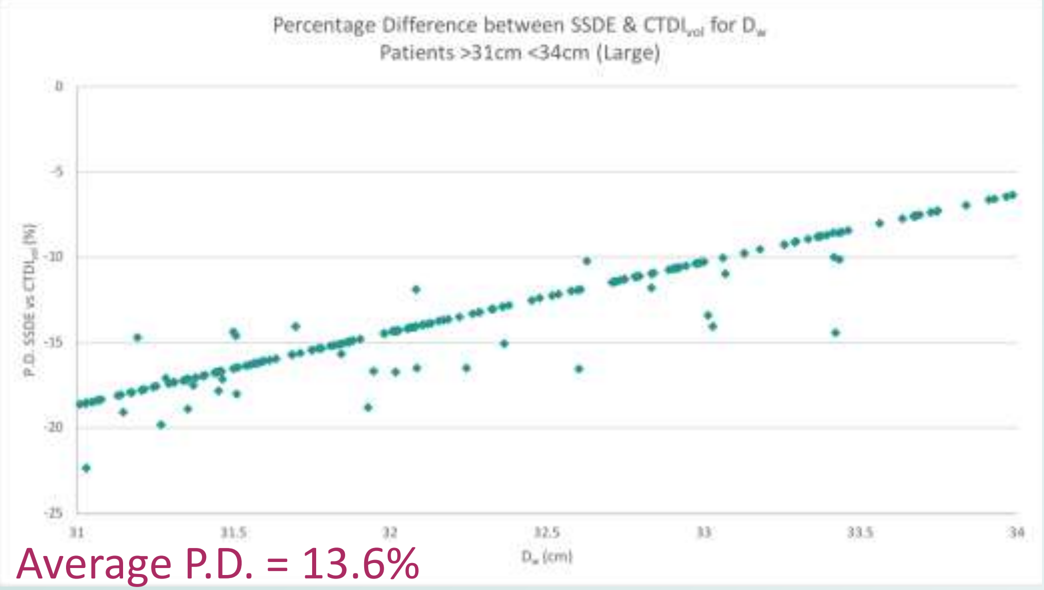

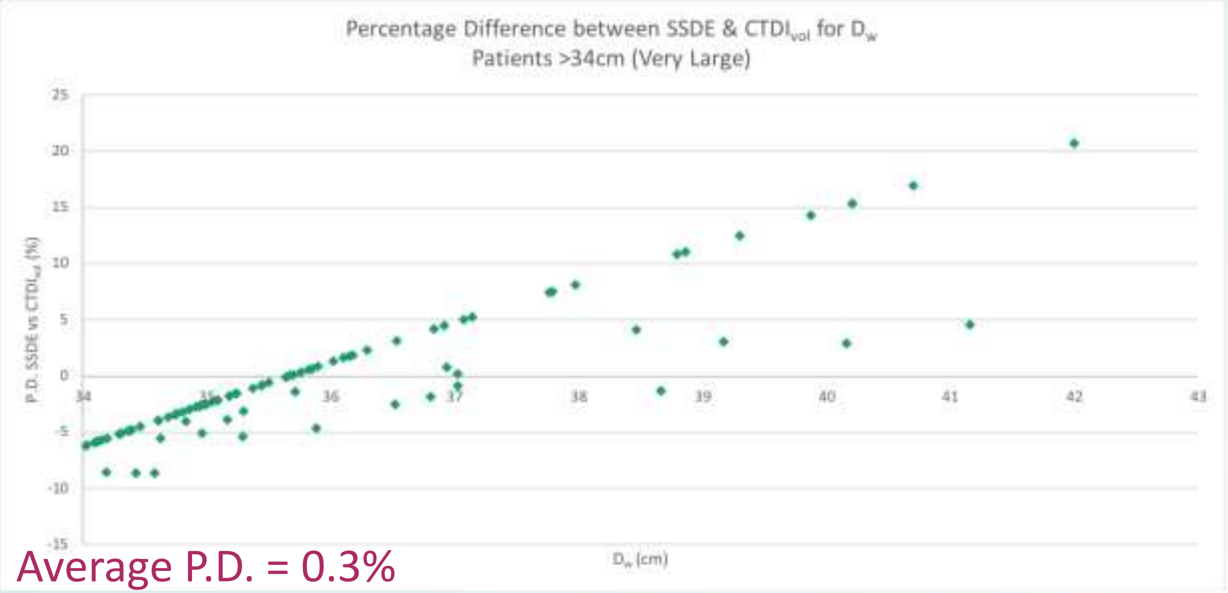

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Summary

- Patient diameter has been calculated using two methods for 823 Abdomen-Pelvis scans
- Size-Specific Dose Estimates have been calculated for each scan
- It was found that $CTDI_{vol}$ misrepresents dose for the majority of patient size categories

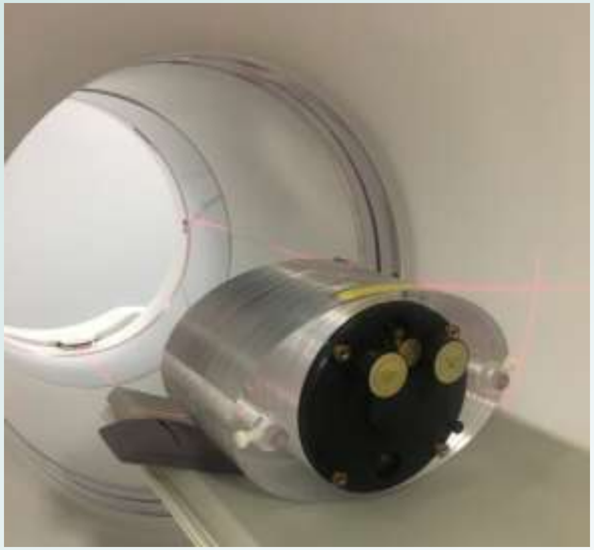
- Obtaining patient diameter from SPRs possible

- Size-optimised CT protocols can be introduced

Work in progress …

Developing Size-optimized Protocols

- Investigation of Noise Index levels for varying patient size
- Elliptical phantoms representing small, medium and large patients
- Catphan fits in centre
- Initial tests performed:
  - $CTDI_{vol}$ vs Noise Index



Developing Size-optimized Protocols