The use of Water-Equivalent Diameter for calculating patient size and Size-Specific Dose Estimates in CT Scans

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BACKGROUND

Computed Tomography (CT) dose is described in terms of two indices:

- $CTDI_{vol}$ (Volume Computed Tomography Dose Index)
- DLP (Dose Length Product = $CTDI_{vol}$ × scan length)

$CTDI_{vol}$ is measured using a 100mm pencil ionisation chamber in cylindrical Poly(methyl methacrylate) (PMMA) phantoms:

- Body: 32 cm diameter
- Head: 16 cm diameter

Body and Head PMMA phantoms with 100mm pencil ionisation chamber
Courtesy of: PTW Dosimetric Solutions for Diagnostic Radiology, Freiburg.

The 32cm diameter phantom is not representative of the body of a patient as it is:

- **cylindrical** – patient is more **elliptical**
- **homogeneous** – patients have **different densities** of material within body
- **made from PMMA** – patients are composed of **different tissue types**
- **of short length** – patient extends beyond the phantom length and contributes to **scattering**

Thus, $CTDI_{vol}$ in its current form cannot be used as a descriptor of patient dose.

AAPM Task Group 204 proposes that $CTDI_{vol}$ be corrected for patient size to give a **Size-Specific Dose Estimate (SSDE)**. Height and weight or BMI are not routinely measured so an alternative method of determining patient size must be used.

Patient size can be estimated in two ways:

- Effective Diameter (D_{eff})
- Water-equivalent Diameter (D_w)

The diameter, x, gives a conversion factor, $y = ae^{-bx}$, which is then used to correct $CTDI_{vol}$.

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

PATIENT SIZE

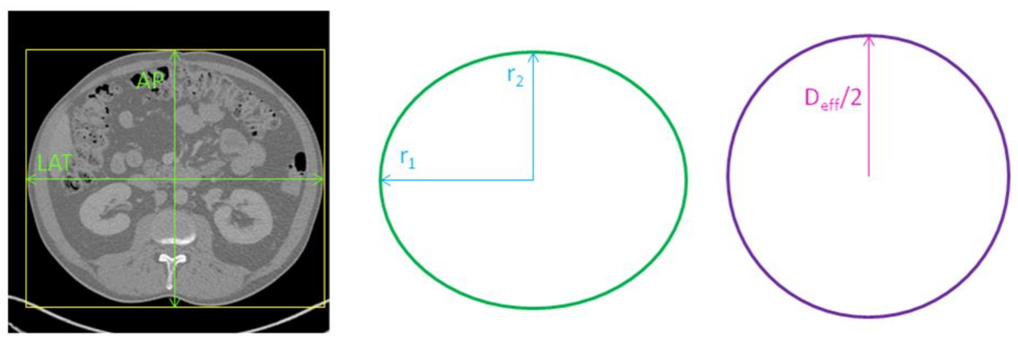
Effective Diameter

Assume patient is elliptical. In an axial image of the patient, the lateral dimension (LAT) gives $2 \times r_1$ and anterior-posterior dimension (AP) gives $2 \times r_2$.

The area of the ellipse is $A = \pi r_1 r_2$

The diameter of the circle with the same area is the effective diameter (D_{eff}) of the patient.

$$D_{eff} = 2\sqrt{\frac{A}{\pi}} = \sqrt{AP \times LAT}$$



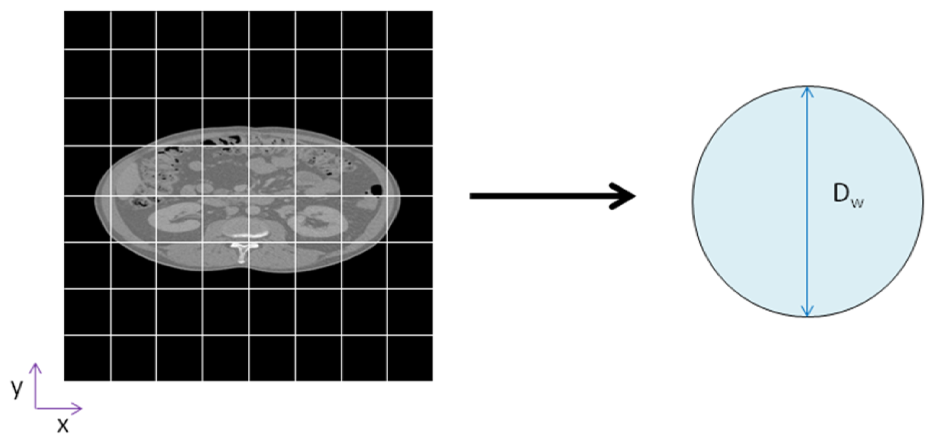
Water-equivalent Diameter

The X-ray attenuation of a patient can be expressed in terms of a cylinder of water having the same attenuation. The diameter of this cylinder is known as the water-equivalent diameter (D_w).

This can be related to the cross-sectional area of the patient on an axial image using the definition of CT number.

$$D_w = 2\sqrt{\frac{A_w}{\pi}}$$

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



CALCULATING DIAMETERS

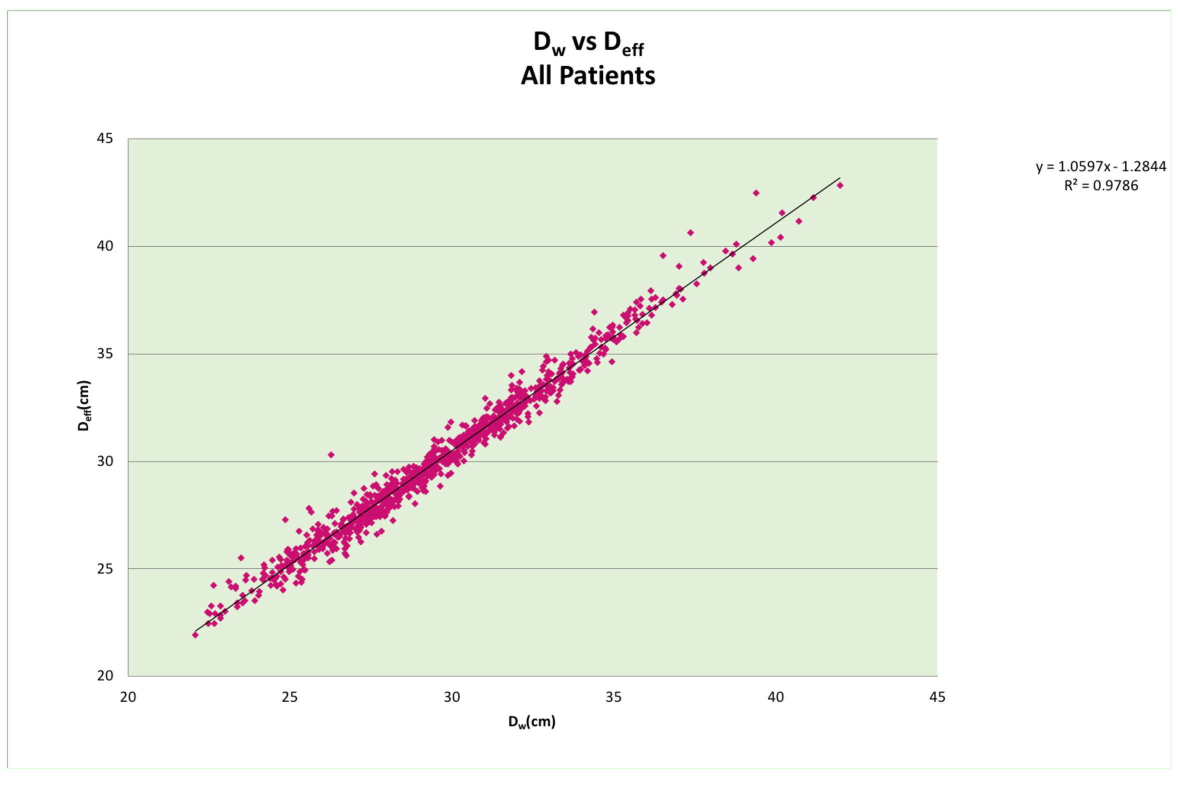
ImageJ is a Java based programme for image processing that is able to:

- handle **stacks** of images
  - such as **slices making up a CT scan**
- detect **edges**
  - isolate patient contour and create **regions of interest** (ROIs), remove patient couch
- calculate **dimensions** of ROIs
  - use to **calculate D_{eff}**
- calculate **areas** & **mean pixel values** of ROIs
  - use to **calculate D_w**
- record **macros**
  - code can be customised to **loop over all slices**

(a) Slice is made binary (b) contour of body detected (c) ROI copied onto original image

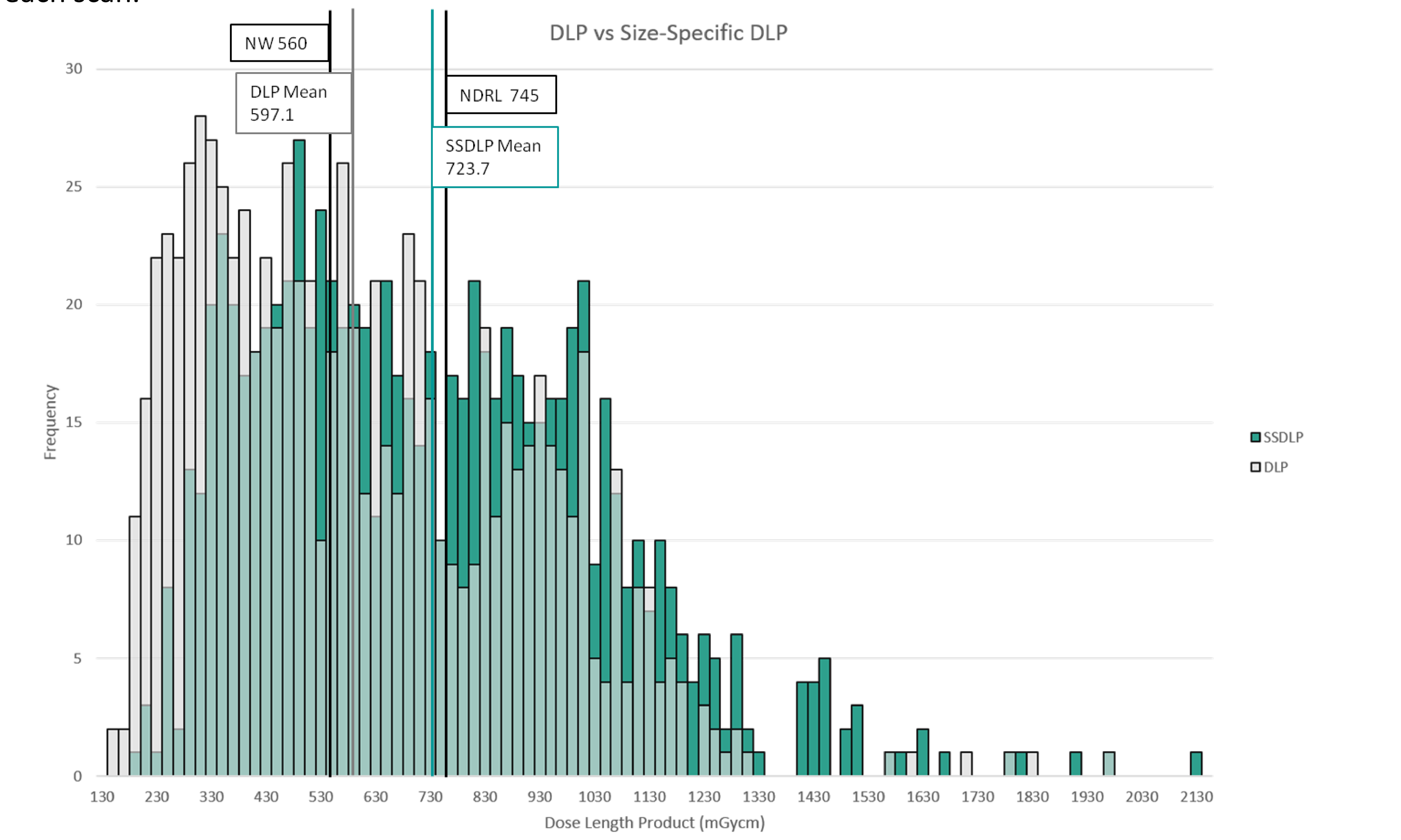
DIAMETER RESULTS

D_{eff} and D_w were calculated automatically using ImageJ for **823 Abdomen-Pelvis CT scans** in Ninewells Hospital and were found to be interchangeable metrics.



SIZE-SPECIFIC DOSE ESTIMATES

SSDEs were determined using the calculated D_w and mean value of $CTDI_{vol}$ given in the Dose Report for each scan.

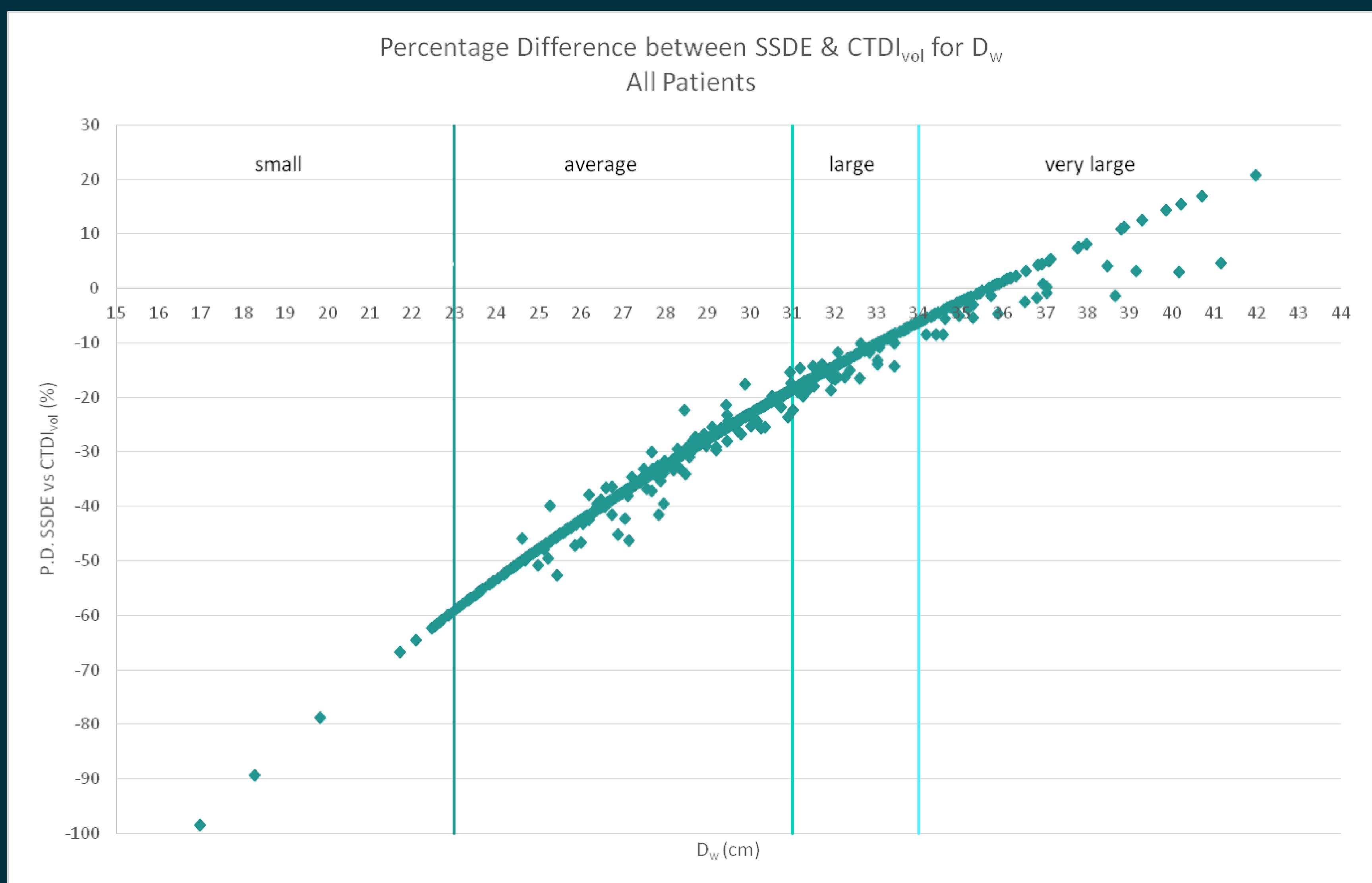


Patient size categories were established and the percentage difference between reported $CTDI_{vol}$ and SSDE was calculated for each category.

It was found that $CTDI_{vol}$ was an underestimation of patient dose for **Small**, **Average**, and **Large** patient categories.

For the **Small**, **Average**, and **Large** patient categories, $CTDI_{vol}$ underestimated patient dose by 68.3%, 33.1% and 13.6 % respectively. $CTDI_{vol}$ was only a suitable indicator for patient dose for those in the **Very Large** category with 0.3% difference between $CTDI_{vol}$ and SSDE.

Category	D_w(cm)
Small	$D_w < 23$
Average	$23 \le D_w < 31$
Large	$31 \le D_w < 34$
Very Large	$D_w \ge 34$



CONCLUSIONS & FURTHER WORK

In an investigation of 823 Abdomen-Pelvis CT scans, taking patient size into account shows $CTDI_{vol}$ and hence DLP underestimates dose for the majority of patients.

Size-optimised scanning protocols can be developed for each patient category to take patient size into account. This can be done by considering scanning Field of View and Image Quality Index alterations for each category. This optimisation would be performed with a view to maintaining an image quality adequate for diagnosis while having a suitable $CTDI_{vol}$ for each size category of patient.