COMPUTED TOMOGRAPHY DOSE INDEX (CTDI)

The principal dosimetric quantity used in CT is the *computed tomography dose index (CTDI)*. This is defined[4] as the integral along a line parallel to the axis of rotation (z) of the dose profile (D(z)) for a single slice, divided by the nominal slice thickness T:

$$CTDI = \frac{1}{T}\int_{-\infty}^{+\infty} D(z)dz \qquad (1)$$

In practice, a convenient assessment of CTDI can be made using a pencil ionisation chamber with an active length of 100 mm so as to provide a measurement of $CTDI_{100}$ expressed in terms of absorbed dose to air (mGy). Such measurements may be carried out free-in-air on or parallel with the axis of rotation of the scanner ($CTDI_{100,\ air}$), or at the centre ($CTDI_{100,\ c}$) and 10 mm below the surface ($CTDI_{100,\ p}$) of standard *CT dosimetry phantoms*. The subscript `n' ($_{n}CTDI$) is used to denote when these measurements have been normalised to unit radiographic exposure (mAs). Further discussion of the quantity CTDI is given in Chapter 2.

Such measurements of CTDI in the standard head or body CT dosimetry phantom may be used to provide an indication of the average dose over a single slice for each setting of nominal slice thickness. On the assumption that dose in a particular phantom decreases linearly with radial position from the surface to the centre, then the normalised average dose to the slice[5] is approximated by the (normalised) *weighted CTDI* ($CTDI_w$):

$$_{n}CTDI_{w} = \frac{1}{C}\left(1/3\,CTDI_{100,c} + 2/3\,CTDI_{100,p}\right) \qquad (mGy(mAs)^{-1}) \qquad (2)$$

where C is the radiographic exposure (mAs) and $CTDI_{100,p}$ represents an average of measurements at four different locations around the periphery of the phantom.

REFERENCE DOSE QUANTITIES

Two reference dose quantities are proposed for CT in order to promote the use of good technique:

(a) Weighted CTDI for a single slice in the standard head or body CT dosimetry phantom:

$$CTDI_w = {}_nCTDI_w \cdot C \qquad \text{(mGy)} \qquad (3)$$

where ${}_nCTDI_w$ is the normalised weighted CTDI in the head or body phantom for the settings of nominal slice thickness and applied potential used for an examination (Equation 2) and C is the radiographic exposure (mAs) for a single slice.

Monitoring of $CTDI_w$ for the head or body CT dosimetry phantom, as appropriate to the type of examination, provides control on the selection of exposure settings, such as mAs.

(b) Dose-length product for a complete examination:

$$DLP = \sum_i {}_nCTDI_w \cdot T \cdot N \cdot C \qquad \text{(mGy cm)} \qquad (4)$$

where i represents each scan sequence forming part of an examination and N is the number of slices, each of thickness T (cm) and radiographic exposure C (mAs), in a particular sequence. Any variations in applied potential setting during the examination will require corresponding changes in the value of ${}_nCTDI_w$ used.

In the case of helical (spiral) scanning:

$$DLP = \sum_i {}_nCTDI_w \cdot T \cdot A \cdot t \qquad \text{(mGy cm)} \qquad (5)$$

where, for each of i helical sequences forming part of an examination, T is the nominal irradiated slice thickness (cm), A is the tube current (mA) and t is the total acquisition time (s) for the sequence. ${}_nCTDI_w$ is determined for a single slice as in serial scanning.

Monitoring of DLP provides control on the volume of irradiation and overall exposure for an examination.

Procedures for estimating $CTDI_w$ and DLP are given below.

METHODS OF DOSE ASSESSMENT TO CHECK COMPLIANCE WITH THE CRITERIA

Comparison of performance against the criteria for each particular type of examination requires assessment of the values of the reference dose quantities associated with the parameters of technique typically used when scanning a standard-sized adult patient. **In the absence of a**

well-defined scanning protocol, typical dosimetric practice should be determined on the basis of the mean results derived for a sample of at least 10 patients for each procedure.

$CTDI_w$ may be assessed directly from Equations (2) and (3) using the results of measurements of $CTDI_{100, p \text{ or } c}$ for the head or body CT dosimetry phantom carried out during routine performance testing. Such measurements may be accomplished using thermoluminescent dosemeters (TLDs) or more conveniently using an appropriately calibrated 100 mm long pencil-shaped ionisation chamber[6]. An indication of typical values of ${}_nCTDI_w$ for particular types of scanner may be obtained from the selected published data given in Appendix I to Chapter 2; a more comprehensive database for a wider range of models is in preparation.

Estimates of $CTDI_w$ may also be made using the typical dose data commonly provided by manufacturers. In accordance with the requirements of the Food and Drug Administration (FDA) in the USA, manufacturers of CT scanners are obliged to report values of CTDI measurements in the standard head and body CT dosimetry phantoms using a specific protocol[7] for which there are important differences from the approach advocated in this Document; such values of $CTDI_{FDA}$ refer to an integration length equivalent to 14 nominal slice thicknesses (rather than 100 mm) and are expressed in terms of absorbed dose to PMMA (rather than air). Similar measurements have also been recommended by the International Electrotechnical Commission (IEC) as part of constancy testing in CT[8]. However, values of $CTDI_{FDA}$ determined in the phantoms will be only slightly less than $CTDI_{100}$ for the largest settings of slice thickness, but more significantly for smaller slice thicknesses. Table 1 gives broad factors[9] to allow the estimation of $CTDI_w$ from such manufacturers data ($CTDI_{FDA}$).

As a practical alternative, estimates of $CTDI_w$ for the head or body CT dosimetry phantom may be derived from simpler measurements of CTDI made free-in-air ($CTDI_{air}$) under similar conditions of exposure (H = head, B = body):

$$CTDI_w = CTDI_{air} \cdot P_{H \text{ or } B} \qquad \text{(mGy)} \qquad (6)$$

where the factor $P_{H \text{ or } B}$ is given by:

$$P_H = \frac{({}_nCTDI_w)_H}{{}_nCTDI_{air}} \qquad (7)$$

and

$$P_B = \frac{({}_nCTDI_w)_B}{{}_nCTDI_{air}} \qquad (8)$$

Measurements of $CTDI_{air}$ are easily accomplished with either the 100 mm pencil-shaped ionisation chamber or a shorter length of TLDs since the tails on the *dose profiles* in air are less significant than in a phantom in view of the lower amount of *scattered radiation*. Typical values of the factor P for a range of scanner models are given in Appendix I to Chapter 2. Further data will be available in a more comprehensive scanner database that is in preparation.

Subsequent estimates of DLP for an examination may be derived using Equations (4) and (5), with knowledge of appropriate values of ${}_nCTDI_w$ for the scanner and details of the particular scanning protocol used. In the case of examinations involving separate scanning sequences in which different technique parameters are applied (such as slice thickness or radiographic exposure, for example), the total DLP should be determined for the entire procedure as the sum of the contributions from each serial or helical sequence.

ASSESSMENT OF EFFECTIVE DOSE

In addition to comparison of performance against reference dose values, there is sometimes a need to assess effective dose[10] for CT procedures so as, for example, to allow comparison with other types of radiological examination. The effective dose for a particular scanning protocol may be estimated from a measurement of $CTDI_{air}$ utilising scanner-specific normalised organ dose data determined for a mathematical anthropomorphic phantom using *Monte Carlo techniques*[11,12]. For types of scanner not included amongst these calculations, appropriate data sets may be selected from those available on the basis of similarity of values of P (Equations (7) and (8))[13].

Alternatively, broad estimates of effective dose (E) may be derived from values of DLP for an examination using appropriately normalised coefficients:

$$E = E_{DLP} \cdot DLP \qquad \text{(mSv)} \qquad (9)$$

where DLP (mGy cm) is the dose-length product as defined in Equations (4) or (5) and E_{DLP} is the region-specific normalised effective dose (mSv mGy^{-1} cm^{-1}).

Values of E_{DLP} appropriate to general regions of the patient (head, neck, chest, abdomen or pelvis) are given in Table 2.

Such an estimate of effective dose may also be derived from a measurement of $CTDI_{air}$ on the basis of Equation (6) and Equations (4) or (5) to determine DLP. Typical values of the factor P are given in Appendix I to Chapter 2 for some scanner models.

TABLE 1 Broad factors to allow estimation of $CTDI_{100}$ from measurements of $CTDI_{FDA}$ in standard CT dosimetry phantoms by manufacturers

Phantom	Slice thickness (mm)	Ratio ${}_{n}CTDI_{100}$ / ${}_{n}CTDI_{FDA}$	
		Centre of phantom	1 cm depth
Head	10	1.0	1.1
	5	1.3	1.2
	3	1.6	1.3
	2	2.0	1.5
Body	10	1.0	1.1
	5	1.4	1.2
	3	1.9	1.3
	2	2.6	1.5

TABLE 2 Normalised values of effective dose per dose-length product (DLP) over various body regions

Region of body	Normalised effective dose, E_{DLP} (mSv mGy^{-1} cm^{-1})
Head	0.0021
Neck	0.0048
Chest	0.014
Abdomen	0.012

Pelvis	0.016

Another quantity in wide-spread use is the particular definition of CTDI given by the Center for Devices and Radiological Health (CDRH)[26] in relation to measurements in a phantom for the purposes of compliance testing of CT systems in the USA:

$$CTDI_{FDA} = \frac{1}{T}\int_{-7T}^{+7T} D(z)dz \qquad (9)$$

where D(z) is the dose at a point z on any line parallel to the z (rotational) axis for a single slice of nominal thickness T.

Under requirements by the Food and Drug Administration (FDA) in the USA, manufacturers of CT scanners are obliged to report values of $CTDI_{FDA}$ for all modes of operation measured according to the protocol devised by CDRH[25]. Values of such measurements in standard CT dosimetry phantoms are quoted in terms of absorbed dose in PMMA. Similar measurements have also been recommended by the International Electrotechnical Commission (IEC) as part of constancy testing in CT[27].

TABLE 1 Analysis of estimated values of $CTDI_w$ from UK CT survey, expressed in terms of absorbed dose to air (mGy)

Examination type	$CTDI_w$ (mGy)							
	Sample size	Mean	SD	Min	25%	Median	75%	Max
Head	102	50.0	14.6	21.0	41.9	49.6	57.8	130
Chest	88	20.3	7.6	4.0	15.2	18.6	26.8	46.4
Abdomen	91	25.6	8.4	6.8	18.8	24.8	32.8	46.4
Pelvis	82	26.4	9.6	6.8	18.5	26.0	33.1	55.2

TABLE 2 Analysis of estimated values of DLP from UK CT survey, expressed in terms of absorbed dose to air (mGy cm)

Examination type	DLP (mGy cm)							
	Sample size	Mean	SD	Min	25%	Median	75%	Max
Head	102	882	332	231	673	795	1045	2087

Chest	88	517	243	72	349	490	649	1304
Abdomen	91	597	281	115	415	525	774	1874
Pelvis	82	443	233	68	266	416	566	1324

TABLE 3 Proposed reference dose values for routine CT examinations, expressed in terms of absorbed dose to air

Examination	Reference dose value	
	$CTDI_w$ (mGy)	DLP (mGy cm)
Routine head[a]	60	1050
Routine chest[b]	30	650
Routine abdomen[b]	35	800
Routine pelvis[b]	35	600

Notes:

a. Data relate to head CT dosimetry phantom (PMMA, 16 cm diameter).

b. Data relate to body CT dosimetry phantom (PMMA, 32 cm diameter).

Figure 1 Histogram of $CTDI_w$ data for routine head examinations in the UK, expressed in terms of absorbed dose to air

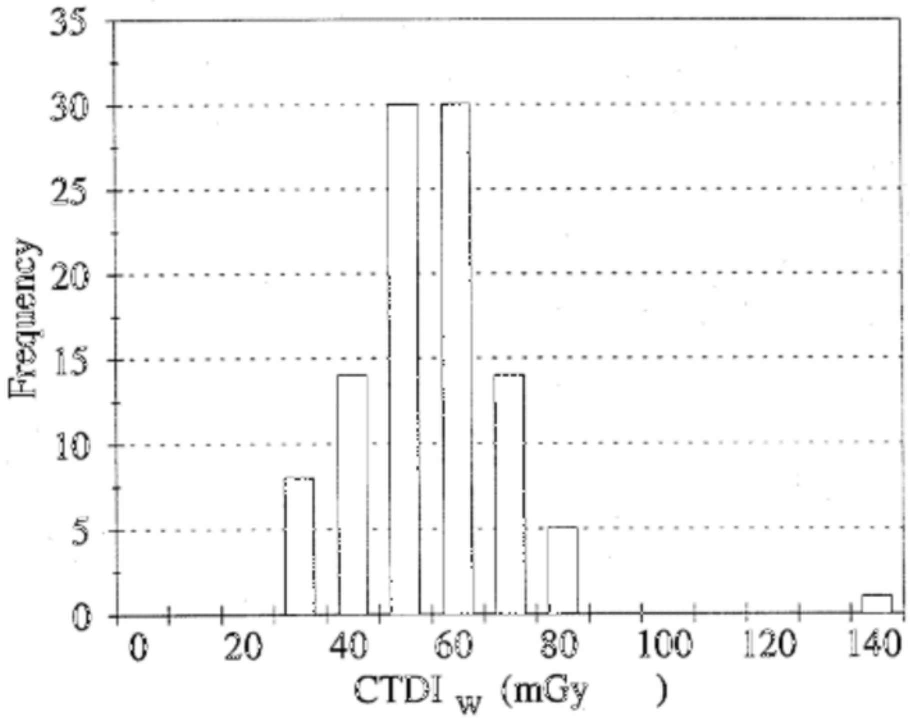


Figure 2 Histogram of DLP data for routine head examinations in the UK, expressed in terms of absorbed dose to air

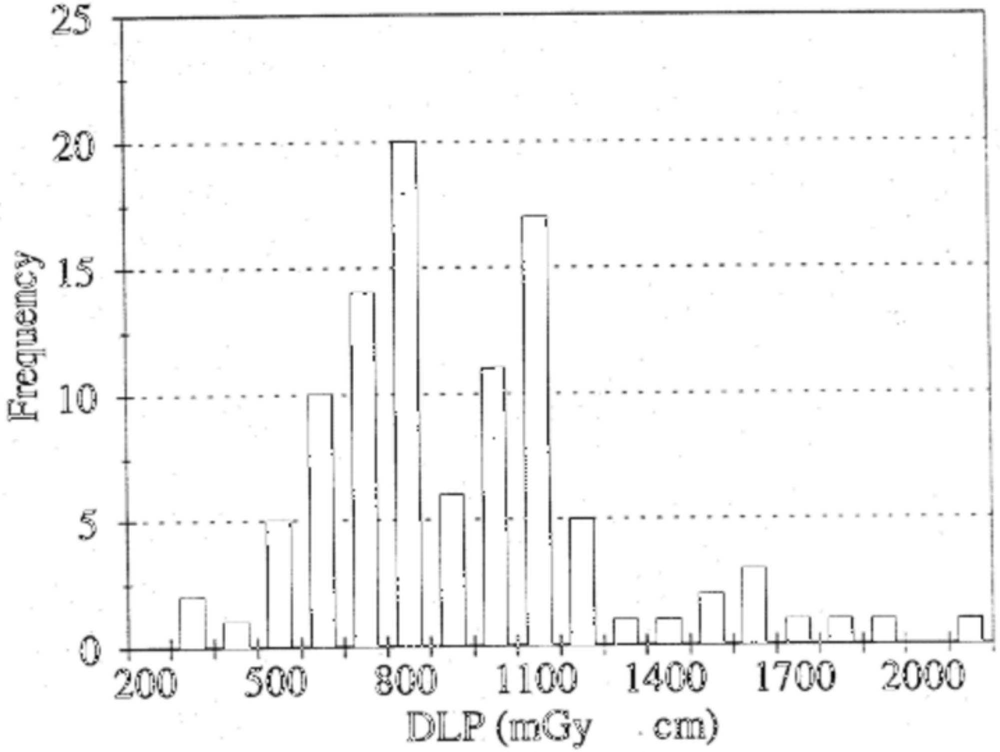
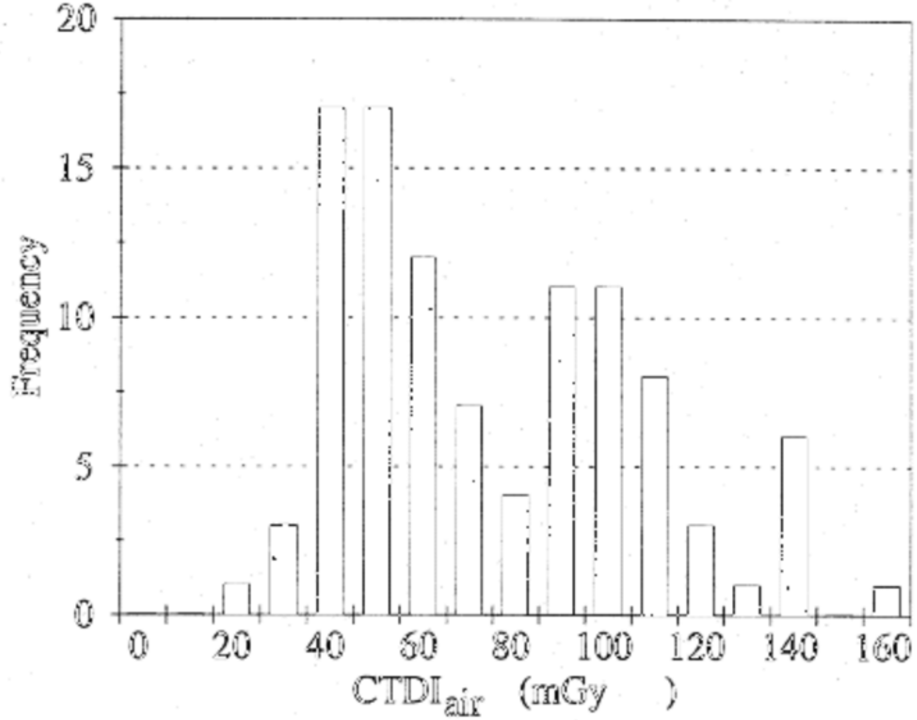


Figure 3 Histogram of $CTDI_{air}$ data for routine head examinations in the UK, expressed in terms of absorbed dose to air



Chapter 2
APPENDIX I

CT SCANNER DOSIMETRY DATA

Data are tabulated below for a selection of scanner models relating to typical values of the normalised dose quantities ${}_{n}CTDI_{air}$ and ${}_{n}CTDI_{w}$, and the factor $P_{H\ or\ B}$, as described in Appendix I to Chapter 1. These illustrative data may be used in the absence of measured data to provide broad estimates of the reference dose quantities for CT. Further data relating to a more comprehensive range of scanners are in preparation.

CT Scanner Dosimetry Data (expressed in terms of absorbed dose to air)

Manufacturer	Model	Applied potential (kV)	Filter option	Focus-axis distance (mm)	Slice thickness (mm)	${}_{n}CTDI_{air}$ mGy /mAs	PMMA Head phantom (16 cm diameter)		PMMA Body phantom (32 cm diameter)	
							${}_{n}CTDI_{w}$ mGy/mAs	P_H	${}_{n}CTDI_{w}$ mGy/mAs	P_B
Siemens	DRG	125	-	700	8	0.087	0.106	1.21	0.076	0.87
	DRH	125	-	700	8	0.089	0.124	1.40	0.089	1.00
	CR	125	-	700	8	0.109	0.128	1.17	0.090	0.83
	AR.HP	130	-	510	10	0.335	0.252	0.75	0.128	0.38
	Hi Q	133	-	700	10	0.195	0.161	0.83	0.093	0.48
	Plus S	120	-	700	10	0.128	0.110	0.86	0.062	0.48
		137	-	700	8	0.161	-	-	0.082	0.51
GE	9000II	120	Head	780	10	0.099	0.060	0.61	-	-
	9000II	120	Body	780	10	0.108	-	-	0.032	0.30
	Pace	120	-	525	10	0.344	0.200	0.58	0.094	0.27
	Max 640	120	-	525	10	0.258	0.158	0.61	0.064	0.25

GE	9800	120	-	630	10	0.204	0.143	0.70	0.063	0.31
Philips	LX	120	-	606	10	0.200	0.160	0.80	0.081	0.41
	CX/Q	120	-	606	10	0.172	0.149	0.87	0.070	0.41
	SR	120	-	606	10	0.204	0.152	0.75	0.082	0.40
Picker	PQ 2000	130	Filter 0[a]		10	0.338	0.287	0.85	0.150	0.44
CGR	12000	130	-	750	10	0.113	0.086	0.76	0.087	0.77

Note: (a) Full field