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Establishment of CT diagnostic reference levels in Ireland

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Objective: To propose Irish CT diagnostic reference levels (DRLs) by collecting radiation doses for the most commonly performed CT examinations.
Methods: A pilot study investigated the most frequent CT examinations. 40 CT sites were then asked to complete a survey booklet to allow the recording of CT parameters for each of 9 CT examinations during a 12-week period. Dose data [CT volume index ($CTDI_{vol}$) and dose–length product (DLP)] on a minimum of 10 average-sized patients in each category were recorded to calculate a mean site $CTDI_{vol}$ and DLP value. The rounded 75th percentile was used to calculate a DRL for each site and the country by compiling all results. Results are compared with international DRL data.
Results: Data were collected for 3305 patients. 30 sites responded with data for 34 scanners, representing 54% of the national total. All equipment had multislice capability (2–128 slices). DRLs are proposed using $CTDI_{vol}$ (mGy) and DLP (mGy cm) for CT head (66/58 and 940, respectively), sinuses (16 and 210, respectively), cervical spine (19 and 420, respectively), thorax (9/11 and 390, respectively), high resolution CT (7 and 280, respectively), CT pulmonary angiography (13 and 430, respectively), multiphase abdomen (13 and 1120, respectively), routine abdomen/pelvis (12 and 600, respectively) and trunk examinations (10/12 and 850, respectively). These values are lower than current DRLs and comparable to other international studies. Wide variations in mean doses are noted across sites.
Conclusions: Baseline figures for Irish CT DRLs are provided on the most frequently performed CT examinations. The variations in dose between CT departments as well as between identical scanners suggest a large potential for optimisation of examinations.

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CT is a powerful clinical tool for the diagnosis and management of patients, and its ability to provide high-quality three-dimensional data has resulted in significant benefits to medical management, enabling faster and more accurate diagnosis and the avoidance of interventional surgical techniques. However, CT is associated with relatively high radiation doses, with a corresponding increased risk of carcinogenesis [1–3]. Therefore, sensible use of the modality requires strict adherence to the tenets of radiation protection—justification, optimisation and minimisation—to ensure that the risk to patients does not outweigh the benefit gained from the technique [4].

At the core of optimisation is the establishment of diagnostic reference levels (DRLs), first proposed by the International Commission on Radiation Protection (ICRP) in 1996 [5] and subsequently introduced into European [6] and Irish legislation [7]. DRLs allow the identification of abnormally high dose levels by setting an upper threshold, which standard dose levels should not exceed when good practice is applied. Excessive doses in CT are not as readily identified through image quality affects, as in standard film-based radiography. Thus, an awareness of typical dose levels allows CT users to quickly identify and address any protocols which do not meet the ALARA (as low as reasonably achievable) principle, thus improving radiographic practice.

Current Irish DRLs are based on international data from 1989 [8] and 1998 [9, 10]. However, since then, CT has undergone dramatic developments, with the introduction of multidetector technology, enabling CT machines to provide higher resolution and faster scan times as well as longer scan ranges. The range of CT examinations available has increased and the number of patients being scanned is steadily growing. Currently in Ireland, over 200 000 CT scans are performed on an annual basis, and this number is growing steadily [11]. The ICRP also recommends that DRLs are based on relevant local, regional or national data [5]. There is therefore an urgent need to update Irish DRLs to more accurately reflect the current range of CT scans being performed as well as the dose levels being received by Irish patients. Previous dose surveys have indicated variations in dose by a factor of 3 from differences in CT scanner design between scanner models [12] and by a factor of 10 [13] in clinical practice, due to differences in local scan techniques and parameter selection. There may be potential for optimisation of CT scan parameters nationwide.

The purpose of this study was to investigate the current radiation doses for CT examinations in adult CT centres throughout Ireland and, based on this data, to propose national diagnostic reference levels for the most

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common CT examinations using two primary dosimetry metrics: dose–length product (DLP) and CT volume index ($CTDI_{vol}$).

Methods and materials

Ethical exemption was granted by the institutional review board of University College Dublin, Dublin, Ireland. A pilot study was conducted in four hospitals to investigate the most commonly performed CT examinations. These hospitals represented two large urban academic teaching hospitals (>500 beds), a private hospital and a rural public hospital (>130 beds). Data derived from radiology information systems (RISs) in each centre was scrutinised to ascertain the number of different CT examinations performed in 2009. This allowed the selection of the most common CT examinations (Table 1).

Survey booklet

All Irish CT sites were asked to contribute to the survey. A survey booklet was designed based on previous work [14] to facilitate collection of pertinent CT scan data and distributed to each site. This involved collecting CT parameters for a minimum of 10 average-sized patients for each CT examination over a 12-week period. Patients were deemed of average size if they weighed 60–80 kg [9]. This survey was conducted during 2010 and the first quarter of 2011. Each site was asked to record the following parameters from the CT console for each patient: peak tube potential, tube current, number of scan phases, $CTDI_{vol}$ and DLP. Further details of the standard CT protocol for each examination were recorded once for each examination; these included the beam collimation, scan field of view, tube rotation time, scan length, pitch, imaged slice thickness and reconstruction algorithms used.

CT dose quantities

Current CT scanners provide two dosimetric quantities at the end of each scan, per International Electrotechnical Commission requirements [15]; namely, $CTDI_{vol}$ and DLP, which are measured in 16 and 32 cm diameter acrylic phantoms. These two parameters have been selected for the promotion of dose optimisation strategies; [16, 17] given their ease of collection, they were the main parameters selected for this study.

$CTDI_{vol}$ is a standardised measure of the radiation output of a CT scanner and although not a direct gauge of patient dose it does allow users to compare different scanners and scan protocols [18]. The SI unit is the milligray and describes the average dose over a volume in either a sequential or a helical sequence [15].

DLP combines the $CTDI_{vol}$ and the scan length to quantify the total radiation dose received by the patient during a CT scan, and is given in milligray centimetres. By also taking into account the number of scan sequences used, total DLP permits a more complete account of the patient dose per examination. Because DLP is directly related to patient risk, it may be used to set reference values for CT examinations [14] and was therefore the primary parameter recorded in this study.

Statistical analysis

Statistical analysis was performed using SPSS v. 18.0 (PASW, Chicago, IL). Quantitative variables are expressed as mean $\pm$ standard deviation The CT data were analysed using descriptive statistics. DLP and $CTDI_{vol}$ data from each site were averaged and the rounded 75th percentile was used to calculate a DRL for each site and also for the country by compiling the dose results from each. Individual results were communicated back to each site to encourage optimisation of scan parameters. Results were compared with national and international DRL data.

Table 1. Pilot study results: frequency (*n*) of CT examinations per CT centre, 2009

	Hospital number				
Examination	1	2	3	4	Total
Head	3438	2801	1304	235	7778
Abdomen and pelvis	2916	2410	301	1640	7267
Chest	2413	1904	310	1525	6152
Chest, abdomen and pelvis	2241	2171	353	690	5455
High-resolution chest	415	400	24	832	1671
Pulmonary angiogram	523	583	115	151	1372
Kidneys–ureters–bladder	142	234	144	295	815
Sinuses	156	107	95	438	796
Cervical spine	146	426	20	98	690
Multiphase abdomen	142	234	54	117	547
Colongraphy	104	100	104	179	487
Cardiac	4	243	80	112	439
Neck	61	155	20	128	364
Biopsy/drainage	105	142	13	46	306
Aorta	12	171	25	51	259
Others (combined total)	515	420	189	84	1208
Totals	13333	12501	3151	6621	35606

Results

Pilot survey

The pilot survey collected RIS data from 35 606 CT examinations performed in 4 CT centres during 2009. The number of examinations from each site is recorded in Table 1. Nine examinations were selected for the main survey because these accounted for 31 728 (89%) of the total number performed.

Returned surveys

There are currently 63 licensed diagnostic adult CT scanners in the Republic of Ireland [11], of which 44 are public and 19 are private. All centres containing these scanners were contacted and 40 agreed to participate in the study. 30 sites returned data for 34 scanners (4 hospitals had 2 scanners), representing 54% of all Irish CT scanners; these included 23 public (52%) and 11 private (58%) centres. All scanners surveyed had multislice capability ranging from 2 to 128 slices (Figure 1). Data were returned for 3305 individual examinations from the requested group; the DLP dose distributions are shown in Figure 2. Not all CT centres performed each CT exam included in the survey or had adequate numbers within the 3-month period to reach the minimum of 10 patients. Therefore, these were excluded from the final data. $CTDI_{vol}$ measurements from the three Toshiba scanners (Toshiba Medical, Europe) were also excluded because these represent maximum values, unlike the averages displayed by the other manufacturers.

Dose results

Table 2 details the descriptive statistics for the surveyed examinations in both $CTDI_{vol}$ and DLP. The proposed Irish DRLs are compared with current European Union (EU) recommendations and other published EU studies in Tables 3 and 4.

The mean $CTDI_{vol}$ and DLP per CT examination were calculated for each site and used to compare doses across CT centres. The CT head exam showed the smallest variation between the minimum and maximum mean doses, with a difference of 250% in $CTDI_{vol}$ and 96% in reported DLP. High-resolution CT (HRCT) scans had the largest variation, with an almost 24-fold difference in both $CTDI_{vol}$ and DLP values (Table 2).

A number of identical scanner models were also included within this study, which allowed comparison between examination protocols used on the same machine in different sites. Doses were reported for six 64-slice, four 16-slice and seven 6-slice Siemens scanners (Siemens Healthcare, Forcheim, Germany), as well as for four 64-slice GE scanners (GE Healthcare, Waukesha, WI). DLP differences of between 38% (head) and 75% (cervical spine) were recorded for the Siemens 64; between 13% (head) and 89% (HRCT) for the Siemens 16; between 6% [CT pulmonary angiography (CTPA)] and 66% (HRCT) for the Siemens 6; and between 10% (head) and 85% (sinuses) for the GE 64.

Discussion

Diagnostic reference levels are a vital part of the optimisation of radiation doses, without which it is quite difficult for operators to readily identify when excessive levels of radiation are being delivered. The simple provision of a set of numerical values can permit radiographers to perform this important review quickly and take corrective actions if necessary. However, these values have to reflect current practices, as well as take account of changes in technology. Current Irish DRLs are based on a UK survey conducted in 1989 [8, 10] and EU data from 1998 [9] which preceded the introduction of multislice scanning. CT has experienced dramatic changes in use and application since then, so this survey

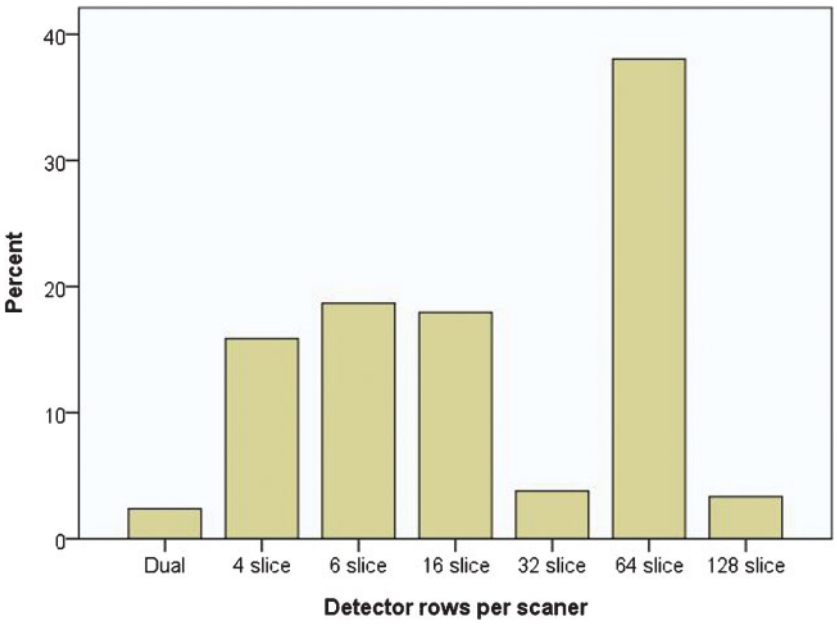


Figure 1. Frequency of CT scanners categorised per manufacturer and number of data acquisition channels.

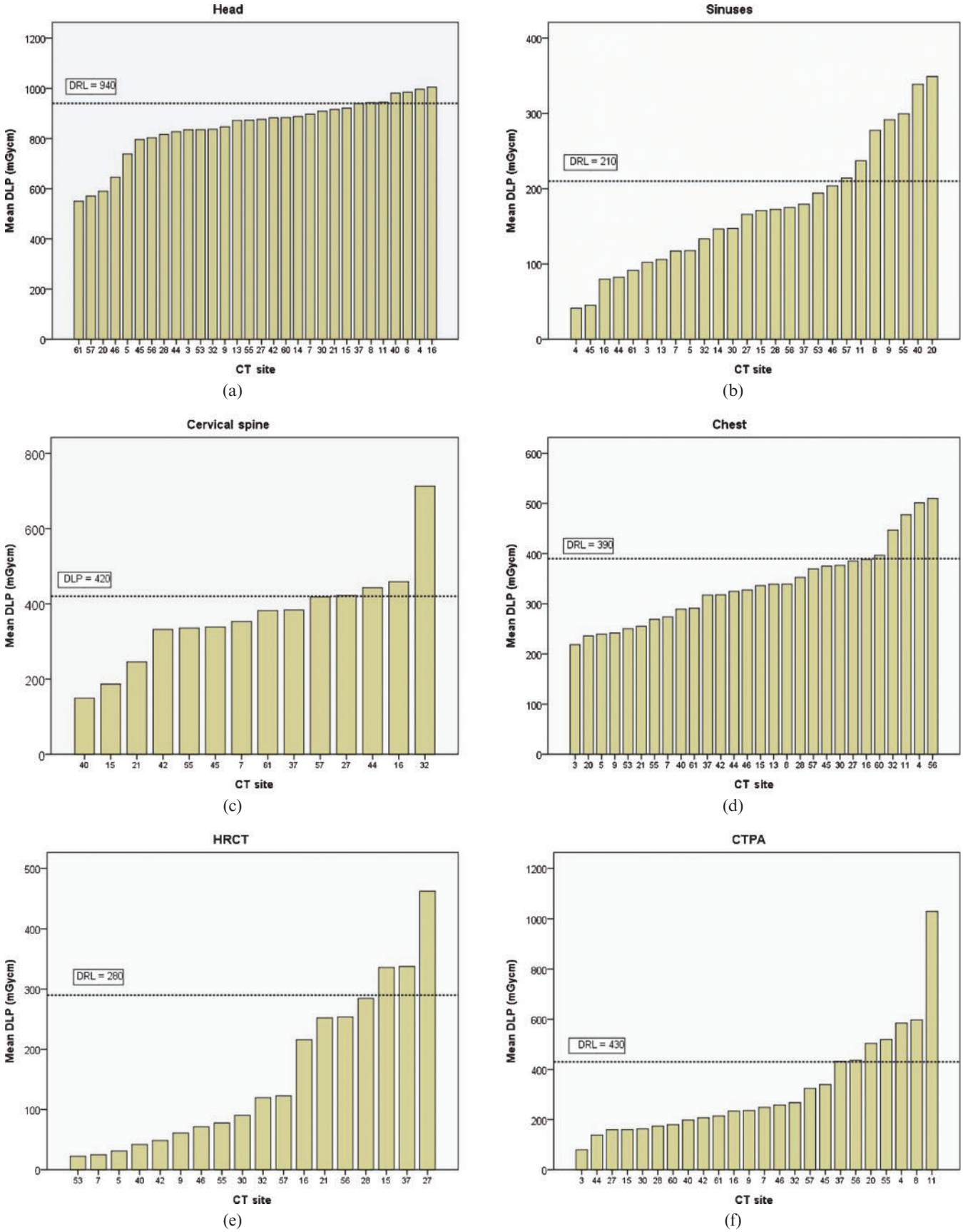
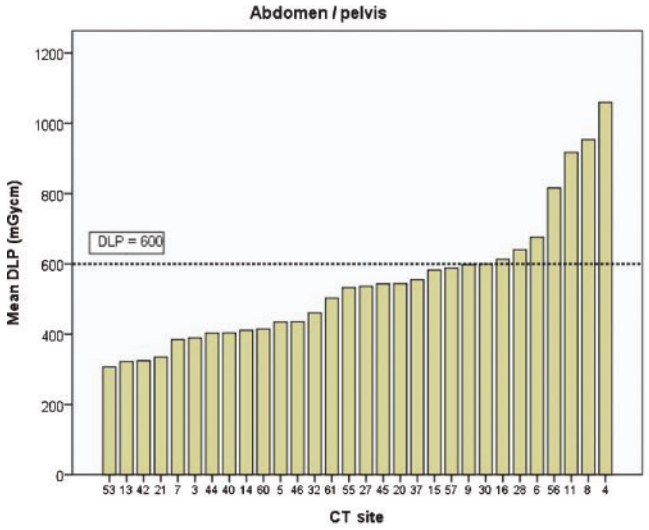


Figure 2. Dose-length product (DLP) distribution for examinations surveyed. (a) DLP distribution for head CT examination; (b) DLP dose distribution for sinus CT examination; (c) DLP dose distribution for cervical spine CT examination; (d) DLP dose distribution for chest CT examination; (e) DLP dose distribution for high-resolution chest CT (HRCT) examination; (f) DLP dose distribution for CT pulmonary angiogram (CTPA) examination; (g) DLP dose distribution for abdomen/pelvis CT examination; (h) DLP dose distribution for multiphase abdomen CT examination; (i) DLP dose distribution for chest, abdomen/pelvis CT examination.



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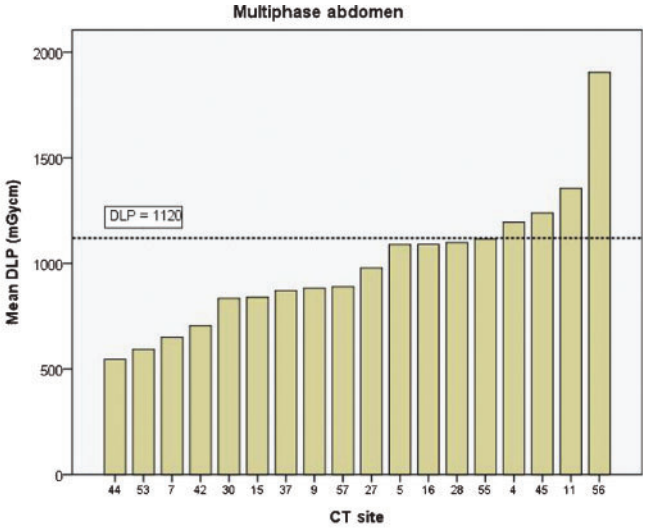

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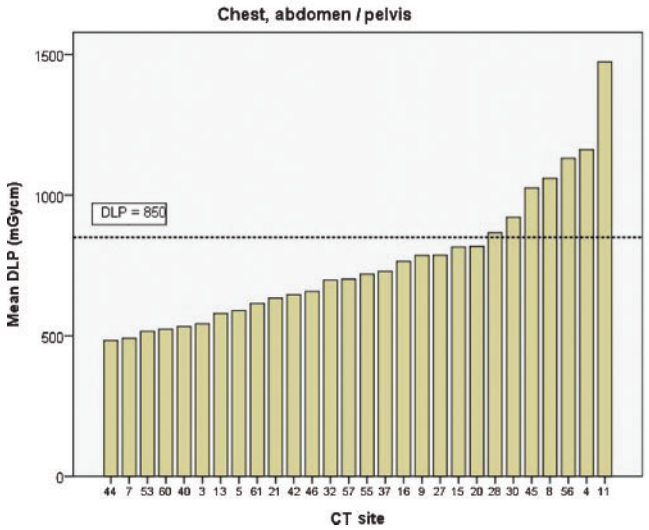

(i)

is significant in both providing up-to-date information and being reflective of local CT practices.

The pilot survey revealed an obvious change in CT practices, with a much wider range of studies being performed currently. This reflects the enhanced capacity of CT scanners to scan longer distances and at finer resolutions, as permitted by spiral and multislice technology. Therefore, in contrast to previous studies [9, 14], this study collected additional data on CT chest, abdomen and pelvis (CAP), CTPA and multiphase abdomen examinations, while omitting both osseous and routine pelvis CT. This emphasises the importance of re-auditing dose limits when technology or examination type changes to more accurately reflect current practices. The nine examinations selected for inclusion in this survey accounted for over 89% of all CT examinations currently being performed in Ireland. The ICRP recommend that DRLs are set for ''common diagnostic procedures'' [5]; therefore, the less commonly performed examinations were not included and the collection of such data may also have resulted in a delay in the time it takes to complete each survey, owing to infrequent scanning. The CT kidneys–ureters–bladder examination was omitted following discussions with the pilot sites because the nature of this examination may vary significantly depending on the clinical indication given (*e.g.* renal stones, renal tumour). However, the rapid proliferation in the use of renal and cardiac CT as well as CT colonography may also merit their inclusion within the common examination category in the near future.

This is the first time Irish-specific data have been collected for CT DRLs and this study demonstrates that current CT dose levels are well below previously recommended values (Table 3) [9, 10]. CT technology has evolved swiftly in the past 20 years and single-slice scanners are now uncommon, with none included in this study. For DRLs to be effective and facilitate optimisation strategies, they have to relate to current practices. Therefore, this study recommends new DRLs which are up to 42% lower than the previous DLP values and also include a number of other CT examinations which are now commonplace in CT departments. Because the previously used metric of weighted CT dose index ($CTDI_w$) has been superseded by $CTDI_{vol}$, this study

Table 2. Descriptive statistics of the dose distribution found across the 34 CT scanners surveyed in DLP (mGy cm) and $CTDI_{vol}$ (mGy)

Exam	*n*	Range	Mean	75th percentile
Head				
DLP	494	550–1078	857 (±121)	940
$CTDI_{vol}$[a]	471	42–106	64 (±15)	66.2
$CTDI_{vol}$[b]	338	32–62	51.3 (±9)	58.4
Sinuses				
DLP	319	41–347	170 (±84)	206
$CTDI_{vol}$	313	1.6–28.5	12.7 (±6)	16.0
Cervical spine				
DLP	189	149–738	362 (±133)	418
$CTDI_{vol}$	173	9.6–22.2	16.8 (±4)	19.4
Chest				
DLP	455	235–615	354 (±103)	393
$CTDI_{vol}$[c]	446	5.3–17.3	8.6 (±3)	9.3
$CTDI_{vol}$[d]	87	7.7–14.4	10.1 (±3)	10.5
HRCT				
DLP	280	22–537	166 (±144)	276
$CTDI_{vol}$	277	0.7–16.3	4.6 (±4)	6.6
CTPA				
DLP	369	131–1029	324 (±208)	432
$CTDI_{vol}$	327	4.1–17.8	9.9 (±4)	12.5
Multiphase abdomen				
DLP	245	524–1904	983 (±307)	1115
$CTDI_{vol}$	227	5.5–37.4	12.9 (±7)	12.6
Abdomen/pelvis				
DLP	489	307–1077	547 (±193)	598
$CTDI_{vol}$	488	6.0–20.5	11.1 (±3)	12.3
CAP				
DLP	467	460–1577	765 (±240)	845
$CTDI_{vol}$[e]	423	4.6–23.3	9.0 (±4)	10.4
$CTDI_{vol}$[f]	351	6.0–17.8	10.2 (±3)	11.6

CAP, chest, abdomen and pelvis; $CTDI_{vol}$, CT volume index; CTPA, CT pulmonary angiography; DLP, dose–length product; HRCT, high-resolution CT.
[a]Base of head sequence.
[b]Head cerebrum sequence.
[c]Lung sequence.
[d]Liver sequence.
[e]Lung sequence.
[f]Abdomen sequence.

also provides updated values of CT scanner output, which are necessary to align with the displayed values of CT scanners in current use. The results shown here are broadly in line with UK [14] and European [13] data (Table 4) regarding multislice scanners, but do emphasise that for optimisation processes to be effective, each region must set and use DRLs appropriate to the practices in their own area.

The reductions in DLP DRLs are to be welcomed and are largely attributable to improvements in scanner technologies such as detector efficiencies, as well as the incorporation of dose-saving software. For instance, automated tube current modulation (ATCM), which varies the amount of tube current delivered depending on patient size [19], has already been shown to reduce CT doses by up to 40% [19, 20] and is available on 85% (29/34) of the scanners surveyed. Sinus (−42%) and chest (−40%) CT examinations noted the greatest DRL reductions, with abdomen/pelvis exams also recording a 23% decrease. Given the high frequency of chest and abdomen/pelvis CT examinations, reductions in mean DLP and thus DRLs will have a significant contribution to reducing the total collective dose to the population and are encouraging results. Because they were not included in previous Irish CT DRLs, CTPA and CAP examinations could not be compared with previous data. However, other international research [14, 21] is available which shows that Irish levels are comparable to and in fact below other jurisdictions.

As expected, the head DRL had a minimal amount of change (−11%) because the technique is still performed predominantly using a sequential scanning technique (29/34, 85%). The cervical spine DRL was similarly reduced, but note has to be made of the fact that there is a large variance in scan protocols observed with many (7/34, 21%) centres surveyed, which chose to routinely scan the full length of the cervical spine (C1–T1) rather than a tightly defined region (usually three vertebral levels). This facilitates full cervical spine CT assessment and is the preferred imaging tool in many centres for high-risk patients, especially when head injury is combined with a neck injury [22]. When both these

Table 3. Proposed Irish DRLs [$CTDI_{vol}$ (mGy) and DLP (mGy cm)] and comparison with European recommendations

	EU 1999 [9]		EU 2004 [13]		Ireland 2010	
Exam	$CTDI_w$[a]	DLP	$CTDI_{vol}$	DLP	$CTDI_{vol}$	DLP
Head	60	1050	60	990	66/58	940
Sinuses	35	360	31	279	16	210
Cervical spine	70	460	—	—	19	420
Chest (and liver)	30	650	12	430	9 (11)	390
HRCT	35	280	9	334	7	280
CTPA	—	—	15	552	13	430
Abdomen/pelvis	35	780	16	726	12	600
Multiphase abdomen	—	—	—	—	13	1120
Chest, abdomen and pelvis	—	—	—	—	10/12	850

$CTDI_{vol}$, CT volume index; $CTDI_w$, weighted CT dose index; CTPA, CT pulmonary angiography; DLP, dose–length product; DRL, diagnostic reference level; EU, European Union; HRCT, high-resolution CT.
[a]Values of $CTDI_w$ are included for comparison with historical data although this descriptor has now been superseded by $CTDI_{vol}$ as a reference dose quantity. EU 1999 is based on reference 9 for single-slice scanners and was adopted as Irish DRLs in 2004 [8]. EU 2004 is based on reference [13] from a European survey in 2001 published in 2004 related to multislice data.

Table 4. Comparison DRLs [$CTDI_{vol}$ (mGy) and DLP (mGy cm)] for other large European surveys

	UK 2003 [14]		Norway 2009 [26]		Switzerland 2010 [21]		Germany 2010 [27]	
Exam	$CTDI_{vol}$	DLP	$CTDI_{vol}$	DLP	$CTDI_{vol}$	DLP	$CTDI_{vol}$	DLP
Head	100/65	930	75	1000	65	1000	65	950
Sinuses	—	—	—	—	25	350	9	100
Cervical spine	—	—	—	—	30	600	—	—
Chest (and liver)	13(14)	580	15	400	10	400	12	400
HRCT	7	170	35	280	—	—	—	—
CTPA	—	—	—	—	15	450	—	—
Abdomen	14	560	15	710	15	650	20	900
Chest, abdomen and pelvis	12/14	940	—	—	15	1000	—	—

$CTDI_{vol}$, CT volume index; CTPA, CT pulmonary angiography; DLP, dose–length product; DRL, diagnostic reference level; HRCT, high-resolution CT.

subgroups were investigated individually, it was noted that the mean DLP recorded when a localised portion of the spine was examined was 307 mGy cm, while when the full spine was examined it was 496 mGy cm. Therefore, the DRL reported here is an aggregate of the two scanning techniques and perhaps it would be more useful for centres to use one or the other, depending on the particular patient presentation. Likewise, the HRCT DLP remains static at 280 mGy cm; but of note, 66% of centres performed this examination using sequential scanning, resulting in a mean DLP of 57 mGy cm, while the remaining centres scanned the entire chest in helical mode, resulting in a mean DLP of 310 mGy cm. This variation in protocols must be attributed to local preferences, with some centres electing to perform selective high-resolution slices at various levels and others scanning the whole chest, despite all patients presenting with the same clinical indication of diffuse lung disease. As with the cervical spine examination, it may be useful for centres that perform sequential scanning to have a local DRL for this protocol to allow further optimisation.

Regarding the range of doses recorded, large variations were evident across the departments surveyed, with 1- to 24-fold differences in mean $CTDI_{vol}$ and DLP reported for the examinations surveyed. This is in line with previous work which has shown that variations may occur depending on CT scanner design [12] and the protocol used [13]. The specific make and model of the CT scanner may lead to some variation in doses owing to inherent differences such as filtration, beam geometry, number of detector rows and scattered X-rays [23]. When identical scanners across different sites were examined here, variations of up to 89% were noted, demonstrating that dose differences are not all attributable to the CT scan design and a large scope for optimisation exists.

One would also rightly expect a certain range of doses if departments are correctly varying parameters for each individual patient—a task made easier by the availability of ATCM software. However, given the relatively small subset of patients involved here (weighing, on average, 60–80 kg), such large variations between sites cannot be accounted for based on patient size differences alone. The main CT parameters that affect dose are peak tube potential, tube current, ATCM use, collimation, scan length and the use of either spiral or sequential scanning. It is evident from the review of each site that large differences in scan parameters exist for each CT examination and that some CT sites performed identical examinations using significantly less radiation. This is an immediate cause for concern and implies an urgent need for optimisation between sites. A number of sites in particular require attention because their mean DLP values consistently exceeded the DRLs proposed here, with two centres surpassing six of the nine examinations surveyed, one exceeding five and another four of the DRLs (Figure 2).

While a number of optimisation strategies have already been proposed for CT examinations [24], it is evident that very few are in clinical use across Irish CT sites. Findings of this study indicate that there is a large potential for dose optimisation across Irish CT departments and especially in those that consistently exceed the proposed DRLs. The introduction of compulsory clinical audit within Ireland [7, 25] may help improve this. This combined with a greater awareness, and adherence to new DRLs should improve the quality of care given to patients and ensure that all clinical radiation doses are kept as low as reasonably achievable.

Limitations

The pilot study was based on data from only four sites and the inclusion of more data would have strengthened the study. Also, this work relied on the accuracy of reported DLP and $CTDI_{vol}$ from each scanner. While these measurements are regularly checked for accuracy by both manufacturers and departmental staff, time restraints precluded this from being further investigated here. Another study [21] has reported that deviations of up to 20% may occur between displayed metrics, which may lead to inaccuracies within the final results. In addition, there was no control for patient height included within this study, which may influence the DLP values reported if variations of scan length are used.

Conclusion

National DRLs for nine of the most common CT examinations in Ireland were calculated from a nationwide survey using a range of multislice scanners. Proposed DRLs were up to 42% lower than previous values and were similar to other international work. However, a large variation in CT doses was revealed,

suggesting that not all departments incorporated DRLs into clinical routine and that a considerable potential for optimisation of CT practices exists. A process of continuous audit to optimise CT scanning is recommended, which can guide CT centres in the appropriateness of their own scanning parameters and also help avoid unnecessarily high doses being delivered.

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