Received:
19 February 2014

Revised:
15 May 2014

Accepted:
26 June 2014

doi: 10.1259/bjr.20140157

Cite this article as:

Sutton DG, McVey S, Gentle D, Hince AJ, MacDonald N, McCallum S. CT chest abdomen pelvis doses in Scotland: has the DRL had its day? Br J Radiol 2014;87:20140157.

FULL PAPER

CT chest abdomen pelvis doses in Scotland: has the DRL had its day?

¹D G SUTTON, PhD, ¹S MCVEY, MSc, ²D GENTLE, PhD, ³A J HINCE, MSc, ⁴N MACDONALD, MSc and ⁵S MCCALLUM, PhD

¹Department of Medical Physics, Ninewells Hospital, NHS Tayside, Dundee, UK

²Department of Medical Physics, Gartnavel Hospital, NHS Greater Glasgow and Clyde, Glasgow, UK

³Department of Medical Physics, Raigmore Hospital NHS Highland, Inverness, UK

⁴Department of Medical Physics, Royal Infirmary of Edinburgh, NHS Lothian, Edinburgh, UK

⁵Department of Medical Physics, Aberdeen Royal Infirmary, NHS Grampian, Aberdeen, UK

Address correspondence to: Dr David G. Sutton

E-mail: d.g.sutton@dundee.ac.uk

Objective: This article reports on a pilot study designed to collect dose data representative of current CT chest abdomen pelvis (CAP) practice in Scotland, make any immediately obvious interventions and to identify if the current UK diagnostic reference level (DRL) of 940 mGy cm is still appropriate. The aims are to identify if a Scotland-wide picture archiving and communication system (PACS)-based dose audit of a number of CT examinations is likely to have value in terms of optimization of patient doses and to comment on the significance of the results in terms of future optimization strategies.

Methods: Dose audit of CT CAP examinations at 32 different scanner sites across Scotland using accepted data collection and analysis methods. The minimum sample size was 30.

Results: Results indicate that CT CAP doses are lower than those previously reported (median, 800 mGy cm,

75th percentile 840 mGy cm) but follow a distribution that is not in keeping with the concept of DRLs as presently understood or implemented.

Conclusion: There is value in a PACS-based dose audit project to provide serial snapshots of patient doses as optimization efforts take place and to revise current knowledge about CT doses. In our opinion, the results call into question whether DRLs or the concept of “achievable dose” are suitable for devising optimization strategies once a certain degree of optimization has taken place.

Advances in knowledge: The results reported here suggest that it may be time to take a different approach to optimization, concentrating on tools that are more refined than the DRL, which may have become more of a compliance tool than an aid to optimization.

Diagnostic reference levels (DRLs) are a well-established tool in the optimization of medical exposures and are used to identify the indistinct border between good or normal practice and bad or abnormal practice.¹ According to the International Commission of Radiological Protection, DRLs are supplements to professional judgment and do not provide a dividing line between “good” and “bad” medicine. They contribute to good radiological practice in medicine.² They are dose levels for typical examinations for groups of standard-sized patients or standard phantoms and for broadly defined types of equipment and are values of measured quantities above which some specified action or decision should be taken. DRLs are usually intended for use as a convenient test for identifying situations where the levels of patient dose are unusually high. They are predicated on the assumption that all images from studies entered into a patient dose audit are diagnostic and came into common use after the publication of the 1984 patient dose survey carried out by the UK National Radiological

Protection Board (NRPB).³ Following publication of this report, and in the context of plain film radiography, a joint Royal College of Radiologists/NRPB report introduced the idea of reference doses and concluded that “some 1300 man Sv could be saved by persuading the 25% of hospitals with the higher doses for the six examinations to change their technique to fall in line with the remaining 75%”.⁴ The concept of the DRL, defined as the 75th percentile of a distribution of mean (or median) doses identified in a large multicentre dose audit followed from this observation. Implicit in the approach is the assumption that the dose distribution has a shape that can be likened to log-normal, that is, it possesses a definite tail to the right. The concept has achieved widespread international acceptance^{5–7} and is now used worldwide.

If one considers the optimization task in medical imaging to be one of identifying the dose that is just high enough and the image quality that is just good enough to achieve

the required diagnosis, then DRLs can be considered to be a tool that can be used to achieve the first step in that process.

Over the past 20 years, many studies have been performed to identify DRLs for a range of examinations at both the national and regional levels using a range of sample sizes. For example, the UK has a restricted set of DRLs that have the Department of Health approval⁸ and a set of more often revised national reference doses (NRLs), published by the Health Protection Agency (HPA—now Public Health England, PHE), that are used by the radiation protection community in lieu of national DRLs for local comparison purposes. There are considerable logistical issues that need to be overcome when collecting and using data that are representative of practice at the national level. These include, for example, (i) ensuring that examinations with the same name are in practice the same examinations, carried out in broadly similar ways, (ii) ensuring that the data collected are the correct data, free from transcription or other error, and (iii) ensuring that the data used are representative of current technology and trends.

Another issue is the identification of candidate examinations to collect data that can be used for comparative purposes. Obvious examinations to consider are those that contribute considerably to the total workload expressed either in pure numerical terms or in terms of radiation dose. Given the increase in CT utilization over the past few years and the consequent increase in population dose arising from CT, CT is therefore a prime candidate.^{9,10} The last reported UK survey of patient doses in CT used data collected in 2003 and was published in 2005.¹¹ The report was comprehensive and included data from one-quarter of all UK scanners, 37% of which had multislice capability of between 2 (about 6%) and 16 (about 2%) slices. There were no scanners with more than 16-slice capability included in the report. This is undoubtedly no longer representative of the range of scanners used in the UK. Since that time, multislice scanners have become ubiquitous and with their advent, the practice of and indications for CT have changed considerably. A more recent survey of CT doses in the UK was commenced by the HPA in 2010, but to date nothing has been published. There are no contemporary published data giving a picture of the distribution of doses in CT in the UK.

Scotland has a national picture archiving and communication system (PACS), and each member of the population registered with the National Health Service (NHS) Scotland has a unique identifier, the Community Health Index. The use of the PACS network as a way of dose data collection would give access to very large data sets, immune from data transcription issues, and would also allow *post hoc* size corrections to be made. The country is therefore well placed to carry out rapid dose audits of CT examinations that can be used to provide up-to-date snapshots of practice. If this were done, then targeted optimization could be carried out at individual hospitals, as and where appropriate. As a precursor to initiating such a project, using the PACS infrastructure, the NHS Scotland Radiation Protection Advisory Group embarked upon a Scotland-wide dose audit of CT chest abdomen pelvis (CT CAP) examinations. The audit was designed to be a pilot project that could be used to identify

what, if any, significant differences there were from the data obtained in the 2003 survey. CT CAP examinations were chosen because they are amongst the most commonly performed in the UK, they result in one of the largest patient doses of any CT examination and also because they were not included in the yet unpublished PHE survey of 2010. Consequently, even if the pilot data set suggested that there was little justification in implementing a PACS-based system, additional data on CT CAP examinations in the UK would be available.

The aim of the pilot study was to collect dose data that were representative of the current CT CAP practice in Scotland out of a total of 66 routinely used for diagnostic imaging, to make any immediately obvious interventions and to identify if the current UK NRL of 940 mGycm was still appropriate. This article describes the survey and results and makes comment on the significance of the results in terms of future optimization strategies.

METHODS AND MATERIALS

The pilot study was conducted over a 9-month period in 2012, and included a total of 32 scanners from across Scotland out of a total of 66 routinely used for diagnostic imaging. The survey focused on CT CAP examinations for standard (average-sized) patients performed using the standard protocol for that scanner. It was not possible to accurately establish the patient's height and weight in all cases, so the only restriction was that they should be of average size. This has potential disadvantages in terms of rigour but is an approach that has been adopted elsewhere.^{12,13} Participating centres were issued with data collection forms and accompanying instructions to ensure that the data collected were representative of standard CT CAP examinations for standard patients.

There were two sections of the data collection forms to be completed. The first section collected scanner and protocol data. This required the hospital name, manufacturer and model of the scanner and local scanner identification to distinguish between scanners at the same site. As the standard protocol for CT CAP examinations may vary between sites it was requested as part of the survey. The principal data requested included the number of scan sequences, the anatomical location of the start and end point for each of the scan sequences and the exposure parameters: tube voltage, current, rotation time, pitch and beam collimation. The second section of the data collection form collected the dose-length product (DLP) for 30 standard patients per site who received CT CAP examinations. The accompanying instructions stated that only patients who received standard CT CAP examinations were to be included in the study. If the patient's examination deviated from the standard protocol, for example, by receiving an additional scan, they must be excluded from the study. Only patients of average size were included; very small and very large patients were excluded. Centres were not asked to weigh the patients but to use their professional judgment on what an "average" sized patient is. The instructions also asked whether patient positioning was the same for all patients participating in the study and was in accordance with the standard protocol, for example, if the standard protocol states that the patient's arms should be above their head for the examination, then only patients who are able to comply with this criterion should be included.

Data analysis was conducted using SPSS® Statistics v. 21 (IBM Corporation, Armonk, NY) and Microsoft Excel® 2011 (Microsoft, Redmond, WA).

RESULTS

The range of scanner manufacturers and models is shown in Table 1. The analysis of the standard protocols showed that the number of sequences performed for CT CAP examinations was 1 or 2; 16 centres used 1 scan sequence (lung apices to symphysis pubis), the remaining 16 centres used 2 scan sequences (lung apices to costophrenic angle and diaphragm to symphysis pubis). Other than the number of scan sequences, the standard protocols were broadly similar. All protocols used an applied potential of 120 kV, and all employed automatic exposure control. Rotation times varied from 0.5 to 0.8 s and the pitch from 0.797 to 1.375.

The variation of mean DLP data amongst the scanners in the survey is shown in Figure 1. Figure 2 shows the minimum, first quartile, third quartile and maximum values of DLP for each scanner. The mean DLP for 27 of the 32 scanners was lower than that of the current UK DRL of 940 mGy cm. There were five scanners that had a mean DLP greater than the DRL. However, of these, only one (number 3 in Figures 1 and 2) was considered to exceed the DRL in a statistical sense when the criteria defined in Institute of Physical Sciences in Engineering and Medicine publication 88 were used, that is, the mean should exceed the DRL by >20% and twice the standard error on its determination.¹ An investigation was performed to identify why the DLP from this scanner exceeded the DRL. The investigation showed that although the standard protocol indicated that mA modulation should be used, it had not been during the audit. The site was re-audited using mA modulation as indicated in the standard protocol. This resulted in the mean DLP for this site being reduced from 1229 to 866 mGy cm, which is lower than that of the DRL. Following this intervention, none of the scanners was considered to exceed the DRL.

Figure 3a shows a dose distribution histogram obtained using the original data prior to the re-audit of scanner number 3 and

clearly shows it as an outlier. The mean of the distribution is 782 mGy cm, the median 789 mGy cm and the third quartile 837 mGy cm. Figure 3b shows the distribution following the re-audit of scanner number 3. The mean DLP is 771 mGy cm, the median 789 mGy cm and the third quartile remains 837 mGy cm. There was no effect on the third quartile of the distribution because it changed the ranking of the DLPs from scanner number 3 from 32 to 26. In a sample size of 32, the third quartile will be about number 24. The rankings following the re-audit are shown in Figure 4, which demonstrates this point.

Since two of the scanners (numbers 14 and 15) employed iterative reconstruction techniques, the data were also analysed following their removal from the cohort. This was carried out to remove the potential impact on the DLP introduced by this type of reconstruction,¹⁴ although inspection of Figure 4 shows that in this case at least, the scanners that used iterative reconstruction did not have the lowest DLPs. The resulting dose distribution is shown in Figure 5. The mean of this distribution is 780 mGy cm, the median 796 mGy cm and the third quartile 840 mGy cm.

Table 2 provides a summary of the descriptive statistics for the dose audit split into three components: (a) results from the initial dose audit prior to the intervention made in the case of scanner 3, (b) all results following the re-audit of scanner number 3 and (c) as in b, but with the results from the two scanners employing iterative reconstruction removed.

DISCUSSION

The study has succeeded in its primary aim of collecting dose data that is representative of current CT CAP practice in Scotland. The audit identified one significant outlier at which practice was modified and dose performance re-audited. A simple analysis shows that the 75th percentile of the distribution of mean DLP following this intervention was 840 mGy cm whether the scanners capable of performing iterative reconstruction were included or not. The pilot study has demonstrated that there are

Table 1. List of scanners by manufacturer and model

Manufacturer	Model	Scanners in sample
GE Healthcare (Little Chalfont, UK)	LightSpeed® VCT	9
	Discovery™ CT750 HD	1
	Optima 660	1
Siemens Healthcare (Erlangen, Germany)	Definition AS+	2
	Definition AS	2
	Sensation 16	1
	Sensation 64	3
Philips Healthcare (Best, Netherlands)	Brilliance 40	1
	Brilliance 64	4
	Ingenuity	2
Toshiba Medical Systems Europe (Zoetermeer, Netherlands)	Aquilion™ 64	6

Figure 1. Variation of mean dose-length product (DLP) amongst the 32 scanners in the survey. Dotted line is the UK reference level for chest abdomen pelvis examinations.

differences from the 2003 study both in terms of the 75th percentile and the shape of the DLP distribution itself. This exercise has been taken as proof of concept that rapid dose audits of CT examinations can be used to provide up-to-date snapshots of practice and perhaps lead to targeted interventions. One such intervention was made in the case of scanner number 3. The ability to apply *post hoc* size corrections when using PACS-based data should further reduce variation due to patient size.

The changes in scanner technology and scanning indications since the UK data collection exercise of 2003 have been quite profound, yet the data show that in Scotland at least, the third quartile of the dose distribution has only changed by about 10%. This itself is not a result that one might necessarily expect given the changes in technology, indications for scanning and the increase in diagnostic information available since then. Nevertheless, it would be tempting to suggest 840 mGy cm as a reference level for Scotland given the lack of data from elsewhere.

Figure 2. The minimum, first quartile, third quartile and maximum dose-length product (DLP) observed at each centre. Dotted line is the UK reference level for chest abdomen pelvis examinations.

Figure 3. (a) Distribution of mean dose-length product (DLP) before re-audit of scanner. Numbers in bars indicate the number of scanners in each bin. Mean DLP is 780 mGy cm; median DLP, 790 mGy cm; and the third quartile DLP, 837 mGy cm. (b) Distribution of mean DLP following re-audit of scanner 3. Numbers in bars indicate the number of scanners in each bin. Mean DLP is 770 mGy cm; median DLP, 790 mGy cm; and the third quartile DLP, 837 mGy cm.

However, DRLs are considered to be levels that should be used to identify the indistinct border between good or normal practice and bad or abnormal practice. The shape of the DLP distribution curve observed in this study does not fit readily with the blunt optimization tool that is the DRL. The typical dose distribution used to determine a DRL has an approximate log-normal appearance with a pronounced positive skew. Data collected in the 2003 NRPB review¹¹ for CT CAP examinations and which provided the existing UK DRL of 940 mGy cm, using data from 36 multislice scanners, demonstrate such a distribution of data. Two recent publications that describe the dose distributions obtained in national data collections of CT data^{12,15}—and which used sample

sizes broadly similar to that used here—have shown distributions of CT dose data that are positively skewed and are not dissimilar in shape to those obtained in the 2003 review. This is most definitely not the case with the data collected in this study. In fact Figures 3b and 5 have a negative skew and do not show any outliers. Figure 4 and Table 2 show that the post-intervention maximum DLP is some two times the minimum, whereas considerably larger values have been observed elsewhere.^{12,15,16} For example, a recent study of CT doses in Ireland shows the same 75th percentile as that observed in this study and a very similar minimum DLP, but the maximum is 50% higher than that observed here, the ratio of minimum to maximum being approximately 3.5.¹⁶

Figure 4. Ranking of the dose-length product (DLP) from each scanner. For example, scanner number 14 has the fourth lowest DLP.

There are at least two possible explanations for the shape of the distribution curve identified here. The first is that in Scotland at least (and assuming that these data are representative of practice in the whole country), the DRL concept is largely redundant in the context of CAP CT at least, as doses have, over the years, been reduced to the extent that its use as a trigger level has become redundant. The second is that the DRL has become exactly what it is not meant to be; a compliance tool, not dissimilar to a dose limit. The implication here would be that interventions have concentrated on ensuring that doses are below the DRL with the view that once that is the case then no

further work need be done towards optimization. Thus, the DRL is seen as an absolute target to be aimed at. Whichever of the two hypotheses is correct, if it is mixture of the two or if there is a different explanation not considered here, the fact is that the utility of a DRL as a tool for optimization, defined as the third quartile of a distribution such as this, is at the very least questionable and at worst inappropriate. It does not identify situations where the levels of patient dose are unusually high, as the DLPs are tightly grouped at the top end of the distribution and, consequently, there is no obvious way of identifying the difference between normal practice and abnormal practice. The

Figure 5. Distribution of mean dose-length product (DLP) following re-audit of scanner 3 and removal of scanners using iterative reconstruction techniques. Numbers in bars indicate the number of scanners in each bin. Mean DLP is 780 mGy cm; median DLP, 800 mGy cm; and the third quartile DLP, 840 mGy cm.

Table 2. Descriptive statistics for the audits undertaken

DLP	Original	Post intervention	Iterative removed
Mean	782	771	780
Median	789	789	796
Minimum	491	491	491
Maximum	1229	1000	1000
5th percentile	521	521	521
25th percentile	708	708	736
75th percentile	837	837	840
95th percentile	1000	995	995
99th percentile	1229	1000	1000
Range	738	508	508

DLP, dose-length product.

“Original” shows the analysis of the data collected; “post intervention” refers to the re-analysis after the re-audit of scanner number 3; and “iterative removed” shows the same but discounting the results for the scanners employing iterative reconstruction techniques.

only conclusion that can be drawn is that some centres produce considerably lower doses than do others. In either case, a more refined approach to optimization seems to be required.

In 1999, the NRPB introduced the concept of the “achievable dose”,¹⁷ the aim of which was to “supplant reference doses so as to encourage departments already below reference dose values to optimise patient protection”. They suggested that in the long term, achievable dose might replace reference dose as an optimization tool and recommended using the mean of a distribution of means as an indicator of achievable dose in the case of conventional radiography at least. (This is not dissimilar to the way in which local DRLs are often set in the UK.) More recently, the NCRP⁵ has suggested using the median dose of a distribution of doses as an indicator of “achievable dose” in all circumstances. The median DLP in this survey was 800 mGy cm, the 75th percentile 840 mGy cm and the maximum 1000 mGy cm. If effort was made to reduce DLPs of the 50% of the centres with DLP >800 mGy cm to below that value, the relatively small decrease required suggests that it might prove possible. It is easy to conjecture that if such were to be the case, then “achievable dose” may well become another target beyond which no further optimization was necessary. The problem would remain the same, so it does not appear that “achievable dose” is useful in this context.

Another potential way forward would be to stop concentrating on the high end of the distribution of doses and start to look at the low end. A recent article concerned with the challenges around the radiation protection of patients in the 21st century makes the point that although DRLs were developed for detecting “outliers”, the need for optimization of the 75% of cases that fall within the third quartile should be stressed.¹⁸ Given that the fundamental premise behind the setting of a DRL is that examinations are diagnostic in the first place, it seems completely reasonable to change the focus of the optimization effort to one aimed at understanding why the first quartile of centres manage to achieve such low doses. It must be stressed that the underlining assumption would be that the images

obtained by the first quartile of scanners are fit for purpose in terms of the diagnostic task. Having analysed the approach taken in the lower quartile, the next step would be to carry out interventions with the aim of bringing the other 75% of centres into some degree of alignment with them. It does not seem unreasonable to suppose that a successful outcome would result in a dose distribution with a more normal (in the statistical sense) looking distribution.

This approach is most feasible in the context of rapid audits carried out at the national level, as they will identify those centres delivering the lowest doses in a short enough time scale to allow meaningful comparisons to be made. Traditional methods of data collection and dissemination strategies with long turn-around times are not ideal for this purpose. Targeted interventions can be made at hospitals where doses are obviously higher than the majority, as has been done here, and analysis of the approach taken at the lowest dose centres can be undertaken to identify what the significant differences are. In this context, more sophisticated dose audit tools, such as those offered by some commercial manufacturers or developed “in house” at some centres may allow more in-depth analysis of the differences between the lowest dose centres and the others. The impact of any change would once again be visible from a patient size-adjusted rapid national audit, carried out via the PACS infrastructure.

CONCLUSION

We have reported on a dose audit of CT CAP examinations at 32 different scanner sites across Scotland using accepted data collection and analysis methods. The study was carried out as a pilot for a nationwide PACS-based dose audit project. The results indicate that patient doses from CT CAP examinations are probably lower than they were in 2003 when the NRPB carried out a UK-wide audit. This is itself not a necessarily expected result given the changes in CT technology and scanning indications since that time. These results of the study have been taken as proof of concept that rapid dose audits of CT examinations can be used to provide up-to-date snapshots of

practice and perhaps lead to targeted interventions. In our opinion, analysis of the results has also called into question the validity of the DRL—whether considered as 75th percentile or as a 50th percentile “achievable dose”—as anything more than an initial optimization tool. The dose distribution identified here suggests that DRLs may have become compliance tools and that a more refined approach to optimization is needed.

ACKNOWLEDGMENTS

The authors would like to acknowledge the assistance of the clinical scientists and radiographic staff at all the centres involved in the study for their help in collecting the data.

FUNDING

This study was supported by the NHS Scotland Health Boards.

REFERENCES

1. IPEM. *Report 88—guidance on the establishment and use of diagnostic reference levels for medical X-ray examinations*. York, UK: IPEM; 2004.
2. ICRP. Radiation protection in medicine. ICRP Publication 105. *Ann ICRP* 2007; **37**: 1–63.
3. Shrimpton P, Wall B, Jones D, Fisher E, Hillier M, Kendall G, et al. *A national survey of doses to patients undergoing a selection of routine X-ray examinations in English hospitals*. NRPB Report R200. Chilton, UK: National Radiological Protection Board; 1986.
4. RCR, NRPB. Patient dose reduction in diagnostic radiology. *Doc NRPB*. 1990; **1**.
5. NCRP. NCRP report 172. *Reference levels and achievable doses in medical and dental imaging: recommendations for the United States*. Bethesda, MD: National Council on Radiation Protection and Measurements; 2012.
6. ICRP. Radiological protection and safety in medicine. ICRP Publication 73. *Ann ICRP* 1996; **26**: 1–54.
7. IAEA. *Radiation protection and safety of radiation sources: international basic safety standards—Interim edition. General safety requirements part 3*. Vienna, Austria: IAEA; 2011.
8. Department of Health. Guidance on the establishment and use of “diagnostic reference levels” (DRLs as the term is applied in the ionising radiation medical exposure) regulations 2000. [Cited 10 July 2014.] Available from: http://webarchive.nationalarchives.gov.uk/20130107105354/http://www.dh.gov.uk/prod_consum_dh/groups/dh_digitalassets/@dh/@en/documents/digitalasset/dh_074099.pdf
9. Brenner DJ. Minimising medically unwarranted computed tomography scans. *Ann ICRP* 2012; **41**: 161–9. doi: [10.1016/j.icrp.2012.06.004](https://doi.org/10.1016/j.icrp.2012.06.004)
10. Hall EJ, Brenner DJ. Cancer risks from diagnostic radiology. *Br J Radiol* 2008; **81**: 362–78. doi: [10.1259/bjr/01948454](https://doi.org/10.1259/bjr/01948454)
11. Shrimpton P, Hillier M, Lewis M, Dunn M. *Doses from computed tomography (CT) examinations in the UK—2003 review*. NRPB Report W-67. Chilton, UK: National Radiological Protection Board; 2005.
12. Palorini F, Origgi D, Granata C, Matranga D, Salerno S. Adult exposures from MDCT including multiphase studies: first Italian nationwide survey. *Eur Radiol* 2014; **24**: 469–83. doi: [10.1007/s00330-013-3031-7](https://doi.org/10.1007/s00330-013-3031-7)
13. Moorin RE, Forsyth R, Gibson DJ, Fox R. Radiation dosimetry assessment of routine CT scanning protocols used in Western Australia. *J Radiol Prot* 2013; **33**: 295–312. doi: [10.1088/0952-4746/33/2/295](https://doi.org/10.1088/0952-4746/33/2/295)
14. Karpitschka M, Augart D, Becker HC, Reiser M, Graser A. Dose reduction in oncological staging multidetector CT: effect of iterative reconstruction. *Br J Radiol* 2013; **86**: 20120224. doi: [10.1259/bjr.20120224](https://doi.org/10.1259/bjr.20120224)
15. Hayton A, Wallace A, Marks P, Edmonds K, Tingey D, Johnston P. Australian diagnostic reference levels for multi detector computed tomography. *Australas Phys Eng Sci Med* 2013; **36**: 19–26.
16. Foley SJ, McEntee MF, Rainford LA. Establishment of CT diagnostic reference levels in Ireland. *Br J Radiol* 2012; **85**: 1390–7. doi: [10.1259/bjr/15839549](https://doi.org/10.1259/bjr/15839549)
17. NRPB. *Guidelines on patient dose to promote the optimisation of protection for diagnostic medical exposures: report of an Advisory Group on Ionising Radiation, documents of the NRPB, Vol. 10, No. 1*. Chilton, UK: National Radiological Protection Board; 1999.
18. Rehani MM. Challenges in radiation protection of patients for the 21st century. *AJR Am J Roentgenol* 2013; **200**: 762–4. doi: [10.2214/AJR.12.10244](https://doi.org/10.2214/AJR.12.10244)