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# Reference dose levels for patients undergoing common diagnostic X-ray examinations in Irish hospitals

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**Abstract.** Wide variations in patient dose for the same type of X-ray examination have been evident from various international dose surveys. Reference dose levels provide a framework to reduce this variability and aid in the optimization of radiation protection. The aim of this study was to establish, for the first time, a baseline for national reference dose levels in Ireland for four of the most common X-ray examinations: chest, abdomen, pelvis and lumbar spine. Measurements of entrance surface dose using thermoluminescent dosemeters (TLDs) for these four X-ray examinations were performed on 10 patients in each of 16 randomly selected hospitals. This represented 42% of Irish hospitals applicable to this study. Results have shown wide variation of mean hospital doses, from a factor of 3 for an anteroposterior lumbar spine to a factor of 23 for the chest X-ray. The difference between maximum and minimum individual patient dose values varied up to a factor of 75. Reasons for these dose variations were complex but, in general, low tube potential, high mAs and low filtration were associated with high-dose hospitals. This study also demonstrated lower reference dose levels of up to 40% when compared with those established by the UK and the Commission of the European Communities for four out of six projections. Only the chest X-ray exhibited a similar reference level to those established elsewhere. This emphasizes the importance of each country establishing its own reference dose levels that are appropriate to their own radiographic techniques and practices in order to optimize patient protection.

The need for radiation dose assessment of patients during diagnostic X-ray examinations has been highlighted by increasing knowledge of the hazards of ionizing radiation. Illustrating the variations of patient dose and their causes is a useful tool in investigating areas in need of dose reduction [1, 2]. Significant variations in patient dose for the same X-ray examination have been evident from many international, national and regional studies [3–5]. These patient dose surveys have provided important information on the levels of patient exposure and provided an insight into the causes of their variation: patient attributes, radiographic procedures, technical and equipment factors, exposure parameters and the level of quality assurance in place. There is considerable evidence that substantial reductions in medical exposures are possible without detriment to patient care [2]. In order to achieve this, there is a requisite for guidance on appropriate levels of patient exposure [5]. In view of these wide variations in patient dose levels for the same X-ray examination, *e.g.* up to a factor of 100 [6, 7], the International Commission on Radiological Protection (ICRP) has recommended the use of reference dose levels (RDLs) in diagnostic radiology [8]. It has also proposed that RDLs should be the result of optimization in radiation protection and should be used as an aid to keeping doses as low as reasonably achievable [7, 9, 10]. Diagnostic reference dose levels have been defined in European legislation [11] as: ''dose levels in medical radiodiagnostic practices or, in the case of radio-pharmaceuticals, levels of activity, for typical examinations for groups of standard-sized patients or standard phantoms for broadly defined types of equipment''. The purpose of RDLs, according to the Commission of the European Communities (CEC), is to encourage departments to investigate their patient radiation dose levels [12]. If these doses exceed the recommended RDL, then departments should investigate the causative factors of the high doses [12]. Reference levels should result from a broad spectrum of defined types of equipment to be widely applicable because the performance of X-ray procedures, equipment and thus resulting patient doses can vary considerably within an X-ray department and between hospitals [9, 13].

With the implementation of EU Directive 97/43/Euratom into Member State law by May 2000, all radiology departments will have a legal obligation to promote the use of RDLs.

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Consistently high departmental doses will result in either an acceptable justification for the dose or revisions in technique or equipment to bring radiation doses in line with other hospitals [12]. While RDLs have been established in the UK and Europe, Irish reference levels have never been established. It is therefore unknown whether the RDLs recommended by the IPSM/NRPB/COR [2] and the CEC [12] are applicable to Irish radiographic practice since, according to Oritz et al [14], universal RDLs may not be suitable for all countries. The aims of this study are to investigate the current levels of patient radiation dose in Irish hospitals, to establish reference dose levels for the chest, abdomen, pelvis and lumbar spine X-ray examinations and to compare them with those already established elsewhere.

## Methodology

The ICRP, the CEC and the National Radiological Protection Board (NRPB) [1–12] have established internationally accepted guidelines and criteria for the measurement of patient radiation doses to which this study has referred for guidance.

To establish the number of hospitals required to represent a normally distributed mean of X-rays in Irish hospitals, a statistician was consulted (Personal communication, O'Reilly 1997). A random sample of 16 hospitals was chosen from all relevant hospitals. The 16 hospitals represented 42% of the sample population. The random sample provided a wide geographical distribution, with all but one Health Board represented and a range of hospital sizes necessary to represent typical doses delivered to patients throughout the country. Within each hospital, information was collected on the generator, tube, grid, automatic exposure control (AEC) device, tabletop, film–screen type and speed, and type of quality assurance programme in use.

Measurements were taken on 10 patients for each projection (with the exception of the lateral lumbar sacral junction (see below)) in each hospital, as recommended by IPSM/NRPB/COR [2] and the CEC [12], to represent typical clinical practice within a hospital. Measurements were carried out in the same room within a 6-week period for each projection. Adult patients weighing within $\pm 13$ kg of 70 kg were sampled; the mean weight of the total sample was 69.9 kg. For each exposure, details of the patients weight, height and sex were recorded along with the exposure factors, focus-to-film distance (FFD) and the use/non-use of an AEC device [15]. Only films that were considered diagnostic by the radiographer were accepted for this study. This ensured that all dose levels used to establish reference dose levels were representative of a diagnostic image.

Entrance surface dose (ESD) was used to assess radiation dose to the patient for the postero-anterior chest, abdomen, pelvis and lumbar spine examinations. Lithium borate thermoluminescent dosemeters (TLDs) were used, which were obtained from and calibrated by the NRPB. Two sets of control dosemeters were used. One set was dispatched with each batch of TLDs to provide an estimate of the background signal for the batch so as to compensate for the inherent noise in the measurement system and for any exposure of customer dosemeters to other sources of radiation. The second set was retained at the NRPB to determine a system sensitivity factor for the batch of dosemeters.

The TLDs were placed behind the control panel, where radiographers removed an unexposed TLD and placed it on the entrance surface of the patient at the centre of the X-ray beam during exposure. Each TLD was then attached to a form with the patients details, exposure factors used, the FFD, use of the AEC device and whether or not the film was accepted. The dosemeters were read by the NRPB using a Toledo 654 TLD reader. Dose estimates provided by the NRPB for each TLD are traceable to the UK national standard of ionizing radiation to air using a methodology that conforms to the International Standards Organization [16]. Overall uncertainties at the 95% confidence level were less than $\pm 12\%$ for measurements in the range 0.5–1000.0 mGy and less than $\pm 25\%$ for measurements in the range 0.1–0.5 mGy. Owing to the low doses received in chest radiography, the TLDs were exposed twice. For any dose recorded below 0.1 mGy, the uncertainty was above $\pm 25\%$. A number of the TLDs were exposed to a known dose by the Radiological Protection Institute of Ireland (RPII) and sent to the NRPB to be read. This served as a method of verifying the results and uncertainties. The results were within the uncertainties specified by the NRPB. All dosemeters were returned to the NRPB within the required 8 weeks of issue.

All relevant data were statistically analysed. Dispersion and central tendencies of frequencies were used to analyse individual patient dose. The Scheffe $F$ test for one-way analysis of variance (ANOVA) was carried out on the mean patient doses between hospitals. A $p$-value $\leqslant 0.05$ was used to determine statistically significant results.

## Results

Analysis was made on 884 valid ESD measurements throughout the 16 hospitals. Only 12 of the hospitals undertook the lumbosacral joint

**Table 1.** Distribution of entrance surface dose values (mGy) for individual patients for the six projections

| Examination | Projection | Min. | Mean | Max. | Standard deviation | Min./Max. ratio |
|---|---|---|---|---|---|---|
| Chest | PA | 0.015 | 0.219 | 0.645 | 0.13 | 43 |
| Abdomen | AP | 0.5 | 4.75 | 18.3 | 3.4 | 37 |
| Pelvis | AP | 1.2 | 5.63 | 26.5 | 3.6 | 22 |
| Lumbar spine | AP | 0.27 | 6.47 | 20.3 | 3.6 | 75 |
| | Lateral | 1.81 | 16.85 | 67.1 | 10.0 | 37 |
| | LSJ | 1.5 | 36.91 | 102.0 | 22.0 | 68 |

AP, anteroposterior; PA, posteroanterior; LSJ, lumbosacral joint.

projection of the lumbar spine X-ray examination and not all hospitals had 10 patients for the lumbosacral junction projection within the specified time frame. Numbers of males and females were evenly divided. The distribution and mean values of ESD for individual patient exposures are presented in Table 1. Minimum/maximum ratio of ESD for individual patients ranged from 22 for the pelvis to 75 for the anteroposterior lumbar spine. Variation of mean hospital dose was not as great. The range of mean hospital dose varies from a factor of 3 for the anteroposterior lumbar spine to a factor of 23 for the chest X-ray (Table 2).

The range of tube potential, mAs, film–screen speed, FFD and filtration used across all hospitals for each projection is shown in Table 3. Only three hospitals used a low tube potential technique for the chest X-ray. Two hospitals employed filtration below the legal requirement of a minimum of 2.5 mm Al. Two hospitals used digital radiography for the chest X-ray examination and only one hospital used digital radiography for all X-ray examinations. Film–screen speeds quoted in the table are from the manufacturers and do not represent actual speed measurements. The reference levels, set at the 75th percentile of mean hospital doses, along with mean hospital dose distribution are shown in Figures 1a–f.

## Discussion

Wide variations in patient dose within and between hospitals were demonstrated (Tables 1 and 2). The reasons for the dose variations are multifactorial: patient weight, exposure factors, radiographic technique, FFD, film–screen speed, equipment type and processing performance [17]. However, the weight restrictions imposed in this study should minimize the contribution of patient size to the mean dose variability [18]. Variations in dose within a hospital room emphasize the importance of a quality assurance programme, so that inconsistencies and errors in technique and equipment can be discovered early and thus reduce the variation in dose to patients.

The ESDs measured in this study for individual patients ranged from a factor of 22 to a factor of 75 (Table 1). A Malaysian study [19] showed that it is possible to achieve much tighter control on patient dose variation, demonstrating factors of 5 to 30. The causes for the wide variations in patient dose within this study require investigation to reduce the variability and ensure that all patient doses are as low as reasonably achievable. It is worth noting that all hospitals in the Malaysian survey carried out a national quality assurance programme, were all equipped with three-phase twelve-pulse or constant potential generators and all X-ray tubes had a minimum filtration of 2.5 mm Al equivalent.

Mean hospital dose values exhibited less variation than the individual patient doses, ranging between factors of 3 and 4.6, with the exception of the chest X-ray where the dose variation factor was 23. This variation was generally lower than that described previously. None the less, the statistical analysis demonstrated that many significant differences existed

**Table 2.** Distribution of mean hospital entrance surface dose values (mGy) across the 16 hospitals for each of the six projections

| Examination | Projection | Min. | Mean | Max. | Min./Max. ratio |
|---|---|---|---|---|---|
| Chest | PA | 0.017 | 0.218 | 0.396 | 23 |
| Abdomen | AP | 2.27 | 4.7 | 9.81 | 4 |
| Pelvis | AP | 2.93 | 5.61 | 10.18 | 3.5 |
| Lumbar spine | AP | 3.36 | 6.42 | 10.25 | 3 |
| | Lateral | 6.64 | 16.87 | 30.61 | 4.6 |
| | LSJ | 17.97 | 37.13 | 77.55 | 4.3 |

AP, anteroposterior; PA, posteroanterior; LSJ, lumbosacral joint.

**Table 3.** Range of exposure factors, speed, focus-to-film distance (FFD) and filtration used for each projection across all hospitals

| Examination | Projection | kV | mAs | Speed[a] | FFD (cm) | Filtration (mm Al) |
|---|---|---|---|---|---|---|
| Chest | PA | 52–150 | 0.99–20 | 200–400 | 170–200 | 1.0–5.2 |
| Abdomen | AP | 64–90 | 7.08–288 | 200–800 | 90–115 | 1.5–3.2 |
| Pelvis | AP | 64–85 | 12.6–380 | 200–800 | 90–115 | 1.5–3.5 |
| Lumbar spine | AP | 64–90 | 9.63–168 | 200–800 | 90–115 | 1.5–3.5 |
| | Lateral | 72–117 | 10.9–400 | 200–800 | 90–115 | 1.5–3.5 |
| | LSJ | 80–96 | 27.6–500 | 200–400 | 90–115 | 1.5–3.5 |

[a] Digital radiography was used for all examinations in one hospital and used in two hospitals for the chest X-ray.
AP, anteroposterior; PA, posteroanterior; LSJ, lumbosacral joint; kV, tube potential; FFD, focus-to-film distance.

between hospitals over all the projections examined. It was not possible to attribute the cause of a particular significant difference between hospital mean dose values in this study to one factor, but rather to the combination of technical parameters and radiographic techniques employed within a hospital [20]. In general the use of a low tube potential and high mAs values was common in high dose hospitals, as was inadequate filtration. The fact that 18% of hospitals were found to have inadequate tube filtration (<2.5 mm Al) gave rise to concern. In general, 400 speed systems were used in low dose hospitals, although some high dose hospitals did use an imaging system with this speed. It is important to note that only one hospital actually measured the speed of its imaging system, and reliance on manufacturers' data may indicate why some hospitals' doses were not as expected considering their nominal film–screen speed classification [12, 21, 22]. The CEC recommends that film–screen speed is measured as it is one of the most critical factors relating to patient dose [12]. For the chest X-ray examination, one digital department demonstrated the third highest mean ESD while the other had the sixth lowest mean dose. The latter hospital demonstrated the lowest mean doses for all hospitals for two other projections, while the remaining measurements for this hospital were amongst the eight lowest hospitals. The results from these two hospitals indicate that digital systems have the potential of reducing dose if set at optimum performance levels, but otherwise low doses cannot be assumed.

Additional cost is often quoted as the main reason why dose-reducing measures are not implemented. It is worth noting, therefore, that in this study, operator practice appeared to be a major determinant for dose levels, where larger FFDs, more appropriate exposure selection and the efficient use of AEC devices were linked to low-dose hospitals. This confirms the findings of previous workers [18]. Other results from this study also showed that low cost measures, such as increasing the level of filtration or changing to faster film–screen combinations, are effective dose-reducing procedures. Moreover, when departments are considering the purchase of more costly, but effective, dose-reducing devices such as carbon fibre tables, it is important that proper cost–benefit analyses are performed because often, when the capital cost is spread over the life of the new device, the change proves to be highly cost effective in terms of cost per man-Sievert [14, 23].

The mean dose values for this study were between 8% and 42% lower than the mean dose values demonstrated in the UK [2]. It is likely that the film–screen combination had a large influence on the lower doses in this study when compared with the UK. In a UK study [6] only 23% of hospitals had a mean speed greater than 200. This is in comparison with 75% of hospitals in this survey employing speeds greater than 200. However, between 1985 and 1995 the NRPB has demonstrated a 30–40% reduction in ESD levels and emphasized the most important factor in reducing patient doses was the increase in the speed of film–screen combinations from 200 to 400 [13]. Other factors influencing differences between this study and that described elsewhere may include beam energy and the inclusion of a secondary radiation grid: Warren-Forward and Bradley [24] reported that for chest radiology, a gridless low tube potential technique will reduce the dose to the patient compared with a high tube potential procedure employing a grid. It is interesting to note, therefore, that in the UK survey low tube potential techniques (without grid) were generally employed and yet there was a higher mean dose value compared with this study, which mainly employed high tube potential techniques (with grid).

12 of the 16 hospitals surveyed performed either no, or very limited, quality assurance procedures. Hospitals exhibiting the highest variations in patient doses were amongst these hospitals, while those with rigorous QA procedures

showed much less variation. Based on these findings, and on the Malaysian data where a national QA programme coexists with a lower variation than described here, emphasis must be placed on the importance of comprehensive QA programmes within all hospitals. Such programmes would not only help establish whether or not the doses received are within acceptable limits but will also identify deficiencies in equipment performance, deficiencies in staff training

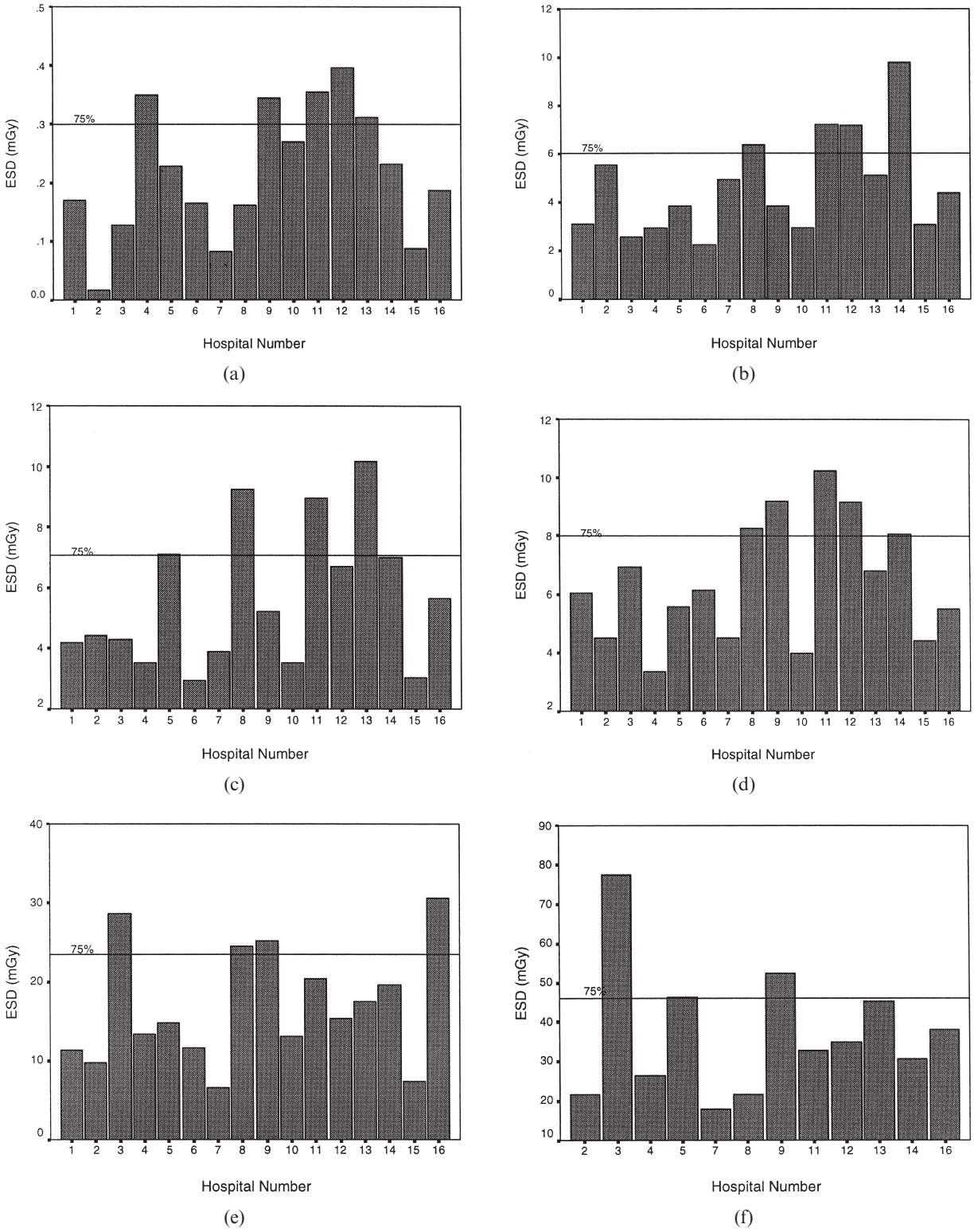


**Figure 1.** Bar charts of mean hospital entrance surface dose (ESD) for the six projections across all hospitals with reference dose levels inserted. (a) posteroanterior chest; (b) abdomen; (c) pelvis; (d) anteroposterior lumbar spine; (e) lateral lumbar spine; (f) lumbosacral junction.

and help to distinguish between high/low dose procedures [25].

Reference dose values determined by the 75th percentile is a well established technique [2, 19] and this study employed this method. The rounded 75th percentile of mean hospital doses for the six projections are demonstrated in Figures 1a–f and Table 4, where it can be clearly seen that some hospitals have been able to achieve mean doses consistently below the RDL value, whereas others have not. It is anticipated that the data provide by this study will now be adopted by the RPII to formulate a National Guidance document on RDLs. Following the publication of such a document, hospitals above the reference levels will then have to undergo an investigation into their high departmental dose, and either justify their high doses or else revise techniques or equipment to bring their radiation doses in line with other hospitals [12, 26].

With the exception of the chest examination, RDLs recorded in this investigation are different from those described in other countries. This study demonstrates an increase of 13% for the lateral lumbar sacral projection and a decrease of 40%, 30%, 20% and 20% for the abdomen, pelvis, anteroposterior and lateral lumbar spine, respectively, compared with UK or CEC levels established in 1986 [1]. If reference levels from neighbouring countries had been adopted in Ireland this would have led to, in the main, fewer hospitals having to examine dose levels that are too high by national standards. This highlights the importance of each country establishing their own RDLs appropriate to their equipment and practice. With changing equipment and techniques that influence patient dose levels [13] it is recommended that dose surveys should be repeated at regular intervals to enable reference levels to be applicable to the current radiographic situation, ensuring optimum patient protection.

**Table 4.** Reference levels (mGy) established by this study, the Commission of the European Communities (CEC) and the UK

| Examination | Projection | This study | CEC (1991) | UK (1992) |
|---|---|---|---|---|
| Chest | PA | 0.3 | 0.3 | 0.3 |
| Abdomen | AP | 6 | 10 | 10 |
| Pelvis | AP | 7 | 10 | 10 |
| Lumbar spine | AP | 8 | 10 | 10 |
| | Lateral | 24 | 30 | 30 |
| | LSJ | 46 | 40 | 40 |

Figures adapted from references [2, 12, 14].
AP, anteroposterior; PA, posteroanterior; LSJ, lumbosacral joint.

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## References

1. Shrimpton PC, Wall BF, Jones DG, et al. Doses to patients from routine diagnostic X-ray examinations in England. Br J Radiol 1986;59:749–58.
2. Physical Sciences in Medicine, National Radiological Protection Board and the College of Radiographers. National protocol for patient dose measurements in diagnostic radiology. Chilton, Didcot: NRPB, 1992.
3. Contento G, Malisan MR, Padovani R, et al. A comparison of diagnostic radiology practice and patient exposure in Britain, France and Italy. Br J Radiol 1988;61:143–52.
4. Warren-Forward HM, Millar JS. Optimisation of radiographic technique for chest radiography. Br J Radiol 1995;68:1221–9.
5. Wall BF. Reference doses for diagnostic medical exposures. Rad Mag 1996;22:29.
6. Shrimpton PC, Wall BF, Jones DG, et al. A national survey of doses to patients undergoing a selection of routine X-ray examinations in English hospitals, NRPB-R200. London: HMSO, 1986.
7. Faulkner K, Corbett RH. Reference doses and quality in medical imaging. Br J Radiol 1998;71: 1001–2.
8. ICRP. Recommendations of the International Commission on Radiological Protection, Publication 60. Oxford: Pergamon Press, 1990.
9. ICRP. Radiological protection and safety in medicine, Publication 73. Oxford: Pergamon Press, 1996.
10. Wall BF. Diagnostic reference levels (including patient dosimetry). Implementation of the ''medical exposures'' Directive. Programme and abstracts. European Commission International Madrid workshop; Madrid; 1998 April 27. The European Commission, 1998.
11. Council Directive 97/43/Euratom. Health protection of individuals against the dangers of ionizing radiation in relation to medical exposure, and repealing Directive 84/466/Euratom. The European Commission, 1997.
12. CEC. European guidelines on quality criteria for diagnostic radiographic images. EUR 16260EN. The European Commission, 1996.
13. Hart D, Hillier C, Shrimpton PC, Bungay D. Doses to patients from medical X-ray examinations in the UK—1995 Review, NRPB-R289. London: HMSO, 1996.
14. Oritz P, Maccia C, Padovani R, et al. Results of the IAEA-CEC coordinated research programme on radiation doses in diagnostic radiology and methods for reduction. Radiat Prot Dosim 1995;57:95–9.

15. Warren-Forward HM, McKeeney DB. Towards a reduction of patient exposure in medical diagnostic radiology. Radiat Prot Dosim 1992;43:283–6.
16. Hillier MC. Quantification of uncertainties for dose estimates provided by the NRPB Patient Dosimetry Service using lithium borate TLDs, NRPB–M575. London: HMSO, 1995.
17. Warren-Forward HM. Patient dosimetry during chest radiography. Radiat Prot Dosim 1995;57: 441–4.
18. NRPB. Patient dose reduction in diagnostic radiology, NRPB 1, No. 3. London: HMSO, 1990.
19. Ng K-H, Rassiah P, Wang H-B, et al. Doses to patients in routine X-ray examinations in Malaysia. Br J Radiol 1998;71:654–60.
20. Leitz WK, Mansson LG, Hedberg-Vikstrom BR, Kheddache S. In search of optimum chest radiography techniques. Br J Radiol 1993;66:314–21.
21. Hardemaal O, Westgaard H. Speed of medical X-ray screen/film/processing system in Danish hospitals. Radiat Prot Dosim 1992;42:115–9.
22. Verdun R, Bochud FO, Valley JF, Lam Thanh O. Determination of the speed of medical radiography screen–film systems. Radiat Prot Dosim 1995;57: 257–61.
23. McNeil EA, Peach DE, Temperton DH. Comparison of entrance surface doses and radiographic techniques in the West Midlands (UK) with the CEC criteria, specifically for lateral lumbar spine radiographs. Radiat Prot Dosim 1995;57: 437–40.
24. Warren-Forward HM, Bradley DA. A pilot study of chest X-ray doses and dose variability within the West Midlands Regional Health Authority. J Radiol Prot 1993;13:267–74.
25. Henshaw ET. Quality assurance in diagnostic radiology—for its own sake or that of the patient. Qual Assur Health Care 1991;2:213–8.
26. Johnston DA, Brennan PC. Diagnostic reference levels. Rad Ire 1998;2:44–5.