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Doses to patients in routine X-ray examinations in Malaysia

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Abstract. A collaborative national survey initiated by the University of Malaya and the Ministry of Health was conducted from 1993 to 1995 to establish baseline patient dose data for seven common types (12 projections) of X-ray examinations in Malaysia. A total of 12 randomly selected public hospitals and 867 patients were included in this survey. The entrance surface doses (ESD) received by the patients were measured using thermoluminescent dosemeters (TLDs) attached to the patient's skin. Histograms are presented showing wide, positively skewed distributions of measured entrance surface doses for each examination. Mean, median, first and third quartile values of ESD and median effective dose are reported. Survey results are generally comparable with those reported in the UK, USA and by the International Atomic Energy Agency (IAEA). The results also provide information on dose level for a lower weight population (mean weight 60 kg) compared with the international reference dose values based on a 70 kg standard. The findings support the importance of the on-going national quality assurance programme to ensure doses are kept to a level consistent with optimum image quality. The data will also be useful for the formulation of national guidance levels as recommended by the IAEA. Furthermore, this study provides patient dosimetry information on healthcare level II countries.

Medical X-rays are by far the largest man-made source of public exposure to ionizing radiation. Worldwide interest in patient dose measurement was stimulated by the 1990 publication of *Patient Dose Reduction in Diagnostic Radiology* by the UK National Radiological Protection Board (NRPB) [1]. Several major dose surveys have been reported, especially from advanced countries [2–8]. However, in developing countries such basic information is still lacking. This survey represents the first organized national dose survey in Malaysia.

Malaysia is a healthcare level II country according to the UNSCEAR definition based on physician densities, (*i.e.* 1000–3000 persons per physician). In 1994 there were 2216 persons per physician in Malaysia [9]. In level I countries there are fewer than 1000 persons per physician. Level I countries, with 25% of the world population, account for some 70% of the diagnostic X-ray examinations [10]. The distribution of medical radiation services in the world is far from equitable. This information from Malaysia will provide a useful contribution to knowledge on patient doses in level II countries. A notable feature of this survey is the information on doses from a generally lower patient weight class (approximately 60 kg) compared with the surveys based on standard-sized patients of 70 kg [2–8].

A pilot study using the indirect method (also known as the semi-empirical method) adopted by Harrison et al [11] was conducted during 1991–1992 to investigate the potential for reducing the radiation dose to patients and to make recommendations on effective methods of patient dose reduction. The result obtained has prompted the implementation of a national dose survey project in Malaysia [12, 13]. A collaborative national survey initiated by the University of Malaya and the Ministry of Health has been conducted from 1993 to 1995 to establish baseline patient dose data for seven routine types of X-ray examinations. In 1992, the Ministry of Health extended its quality assurance programme in radiology (launched in 1987) from 16 major hospitals to 103 hospitals throughout the country [14]. Though it was confined to quality control activities such as tube potential (kV), mAs, sensitometry, image quality tests and reject analysis, the importance of patient dose monitoring was also recognized as an important aspect of the overall programme.

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Survey methods

This survey, basically following the guidelines established by protocols of NRPB [15], was conducted in 12 randomly selected Malaysian public hospitals representing reasonably good geographical spread and size. For each X-ray room, machine specific data such as type, model, waveform, filtration, film–screen combination and output were recorded. Basic equipment quality control including the film processor had been implemented in these hospitals [14]. All hospitals performed daily monitoring of sensitometry, developer temperature and processing cycle time.

The following seven routine types (12 projections) of X-ray examinations were studied: chest (PA, Lat); abdomen (AP); pelvis/hip (AP); skull (AP/PA, Lat); cervical spine (AP, Lat); thoracic spine (AP, Lat); and lumbar spine (AP, Lat). Only cases with diagnostically acceptable images were used in the survey.

For each patient and X-ray unit the following parameters were recorded: sex, ethnic origin, age, weight, height, body mass index, focus-to-skin distance, focus-to-film distance, field size, kVp and mAs. Body mass index (BMI), derived from weight/(height)^2, is a useful classification scheme for the size and shape of a person [16]. To obtain an estimate of the typical dose delivered to an average Malaysian adult patient measurements were made on a representative sample of patients with a mean weight around 60 kg within a range 45–75 kg.

Measurements of entrance surface dose (ESD) were made using individually packed LiF thermoluminescent dosimetry (TLD) chips (TL-100, Harshaw). A chip was placed at the centre of the beam on the patient's skin during the examination. These chips were later read using a TLD reader (Harshaw QS 3500, Bircon). The TLD system used in this survey was calibrated by the Primary Standard Dosimetry Laboratory at the National Radiation Laboratory, New Zealand and found to be capable of performing within recommended levels of precision and accuracy. Calibration procedures recommended by the NRPB [15] were followed. The overall uncertainty was $\leqslant \pm 20\%$ at the 95% confidence level. The calibration fulfilled the following criteria. The standard deviation of the TLD batch was of the order of 5%, and the standard deviation of readings at 0.1 mGy was less than 30%. Cross-calibration was also carried out at the Secondary Standard Dosimetry Laboratory of the Malaysian Institute for Nuclear Technology Research (MINT).

Effective dose for each patient is calculated from ESD using XDOSE [17], a computer program to enable dose calculation for combinations of the 68 radiographic projections given in the software report NRPB-SR262 [18].

Results

All 22 rooms in the 12 hospitals were equipped with three-phase 12-pulse or constant potential X-ray units with a minimum total filtration of 2.5 mm Al equivalent at 100 kVp. All hospitals participated in a quality assurance programme coordinated by the Ministry of Health.

A total of 867 patients were included in this study. Patient information and exposure parameters are shown in Table 1. By careful selection of patients (mean patient weight of 58–61 kg and BMI of 22–24) has eliminated an important factor affecting the variability of ESD. The study sample is younger (mean age 37–49 years) than in the UK survey (ages 47–66 years) [5]. The range of tube potentials for most projections are similar to UK practice [4]. This could be because, traditionally, Malaysia had adopted British radiographic technique.

Descriptive statistics of ESD and median effective dose are given in Table 2. Figure 1 shows histograms of selected projections with first and third quartiles, median and IAEA reference levels indicated. Generally, a widespread, positively skewed distribution with mean values larger than median values is observed for most projections, the exception being for the skull examination where no skewed distribution is observed. A similar trend was also reported in the NRPB 1983–1985 survey [4].

Table 3 shows the maximum/minimum ratio of ESD of individual patients, maximum/minimum ratio of mean ESD among hospitals, interquartile range (ratio of the third quartile to the first quartile) and the coefficient of variation of individual patients. The latter two indices provide information less sensitive to extreme values. ESDs per radiograph for the same type of projection typically range over factors between 5 and 30 for individual patients and between 5 and 10 in the mean value among hospitals. The interquartile range is between 1 and 3; the coefficients of variation range between 50 and 80%. While each hospital has a wide range of ESD for individual patients for each projection, the mean ESD for a given projection does not vary as greatly from hospital to hospital. For example, the hospital with the highest mean ESD for the posteroanterior (PA) chest is 4.6 times greater than the lowest mean ESD.

The variation for individual patients and inter-hospital variation are smaller than the 1983–1985 UK survey [4]. For example, chest PA projection has a maximum/minimum ratio for individual patients of 14.8 and a maximum/minimum ratio of mean ESD among hospitals of 4.6, compared with the corresponding UK values of 47.7 and 7, respectively. Lumbar spine anteroposterior (AP) projection has a maximum/minimum ratio for individual patients of 13.7 and a maximum/minimum

Table 1. Patient information and exposure parameters for seven routine X-ray examinations (12 projections). Mean values and range (in parentheses) are given

Radiograph	Projection	Patient age (years)	Patient weight (kg)	Body mass index	Tube potential (kV)	Mean mAs (mAs)
Chest	PA	44 (14–76)	59 (45–81)	24 (17–37)	79 (55–125)	9 (2–30)
	LAT	49 (15–83)	58 (45–80)	23 (16–35)	88 (65–120)	19 (4–122)
Abdomen	AP	43 (17–75)	60 (45–75)	23 (17–33)	71 (60–85)	57 (13–100)
Pelvis/hip	AP	42 (15–92)	61 (45–82)	23 (18–35)	70 (60–90)	40 (9–80)
Skull	AP/PA	36 (15–85)	58 (45–80)	23 (16–33)	71 (56–87)	38 (5–70)
	LAT	37 (16–92)	59 (45–80)	23 (17–33)	68 (56–81)	32 (7–70)
Cervical spine	AP	42 (15–79)	58 (45–79)	23 (18–31)	66 (50–80)	16 (6–40)
	LAT	41 (14–79)	59 (45–79)	24 (18–32)	69 (60–85)	20 (5–40)
Thoracic spine	AP	37 (14–75)	58 (45–82)	22 (18–29)	72 (60–82)	48 (13–80)
	LAT	38 (15–75)	59 (44–82)	23 (18–29)	81 (63–92)	62 (11–112)
Lumbar spine	AP	43 (15–80)	61 (45–75)	23 (17–31)	77 (60–96)	51 (10–100)
	LAT	44 (14–86)	60 (45–75)	23 (17–31)	89 (60–125)	72 (11–160)

Table 2. Distribution of individual entrance surface dose (ESD) and median effective dose for seven routine X-ray examinations (12 projections) from a random sample of 12 hospitals in Malaysia

Radiograph	Projection	Number	Entrance surface dose (mGy)					
			Min.	First quartile	Median	Mean	Third quartile	Max.
Chest	PA	131	0.05	0.16	0.26	0.28	0.35	0.74
	LAT	62	0.27	0.70	1.17	1.40	2.00	3.80
Abdomen	AP	99	1.67	5.98	9.22	10.00	13.82	24.45
Pelvis/hip	AP	70	1.14	3.81	5.33	8.41	11.08	30.91
Skull	AP/PA	103	0.72	3.11	4.74	4.78	6.85	8.27
	LAT	78	0.42	1.91	3.03	3.34	4.81	7.66
Cervical spine	AP	48	0.37	0.55	0.70	1.02	1.06	3.07
	LAT	46	0.23	0.60	1.49	1.60	2.28	3.96
Thoracic spine	AP/PA	22	2.21	4.79	6.39	7.03	8.72	12.87
	LAT	23	2.66	8.77	15.92	16.54	21.90	39.24
Lumbar spine	AP	88	2.24	5.34	9.06	10.56	14.71	30.68
	LAT	97	4.96	8.99	13.97	18.60	25.12	56.92

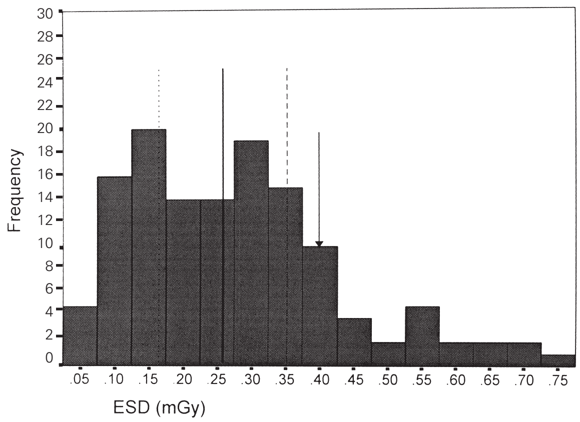
ratio of mean ESD among hospitals of 6.6; the UK values are 71.2 and 6, respectively.

Table 4 compares the median ESD values of this survey with established reference dose values from USA (CRCPD/CDRH) 1992 [19], NRPB 1986 [4], NRPB 1992 [15] and IAEA Basic Safety Standard 1996 [20]. These reference dose values are based on the use of 200 speed class film–screen combinations. It should be noted that the USA survey was carried out using a set of standard phantoms to simulate an average sized patient. The entrance skin exposure (ESE) values have been converted to ESD according to an established method [21]. The reference dose values set forth in the IAEA Basic Safety Standard [20] are based on those of the Commission of the European Communities (CEC) [22].

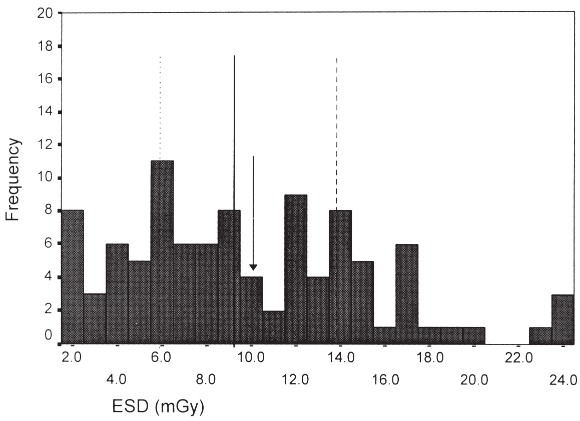
The median ESD values for all the projections in this survey are below the IAEA reference dose levels. Both chest PA and lumbar spine lateral projections have the lowest number of doses greater than the IAEA reference levels (23.6% and 21.6%, respectively). Both skull AP/PA and lateral projections have the largest number of doses greater than the IAEA reference levels (45.6% and 50%, respectively). Abdomen AP, thoracic spine AP/PA, and lumbar spine AP also have a large number of doses exceeding IAEA reference dose levels (43.0%, 40.0% and 46.6%, respectively). Comparison of cervical spine is not possible as there are no available reference dose values.

Discussion

The results of this national dose survey provide valuable baseline data for Malaysian patient doses. The very wide variations in patient dose for the same types of X-ray examination carried out on



(a)



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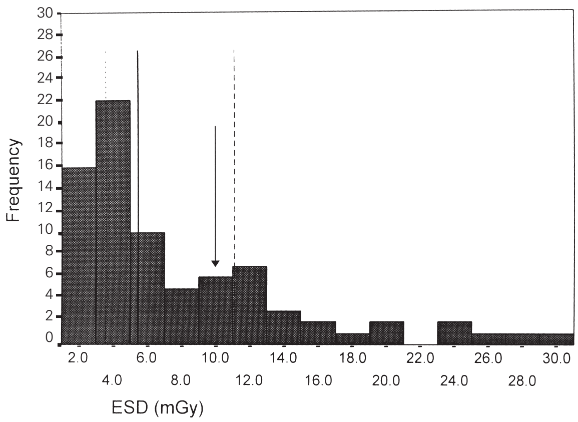

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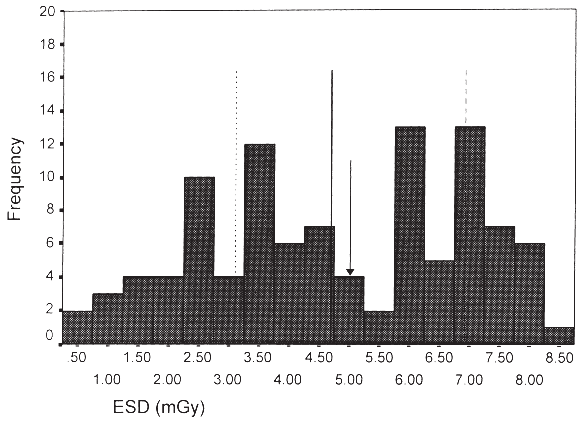

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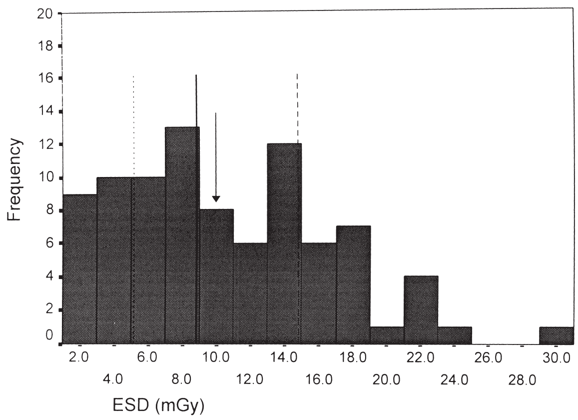

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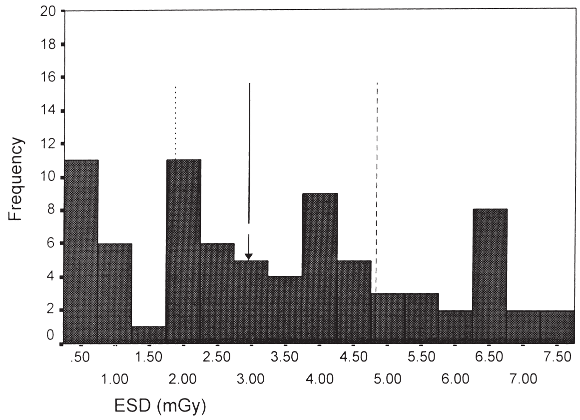

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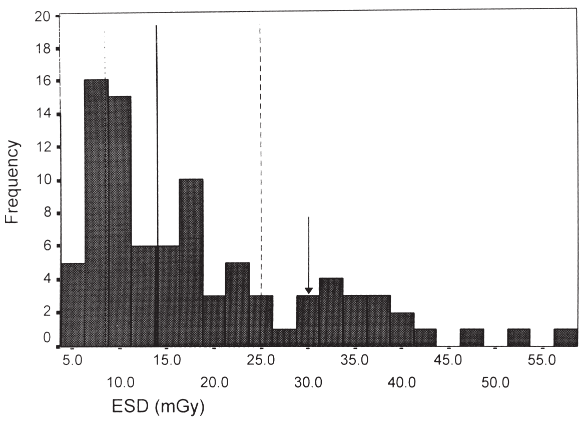

(g)

Figure 1. Histograms of entrance surface dose (ESD) per radiograph for selected common X-ray projections in Malaysia. First and third quartiles are indicated by short and long dotted lines, respectively, while median values are indicated by solid lines. IAEA reference values are indicated by short solid lines with arrowheads. (a) Chest PA; (b) abdomen PA; (c) pelvis PA; (d) skull AP/PA; (e) lumbar spine AP; (f) skull Lat; (g) lumbar spine Lat.

Table 3. Maximum-to-minimum ratios, interquartile range and coefficient of variation of ESD

Radiograph	Projection	Ratio max./min. for individual patients	Ratio third/first quartile for individual patients	Coefficient of variation (%) for individual patients	Ratio max./min. of mean ESD among hospitals
Chest	PA	14.8	2.2	71	4.6
	LAT	12.7	2.9	57	5.4
Abdomen	AP	14.7	2.3	60	6.1
Pelvis/hip	AP	27.2	2.9	82	10.0
Skull	AP/PA	11.6	2.2	46	5.2
	LAT	18.1	2.5	63	11.6
Cervical spine	AP	8.3	2.2	78	5.0
	LAT	17.6	1.2	69	6.6
Thoracic spine	AP/PA	5.8	1.8	46	4.7
	LAT	14.8	2.5	68	10.6
Lumbar spine	AP	13.7	2.8	59	6.6
	LAT	11.5	2.8	67	5.5

Table 4. Comparison of ESD with international established reference dose values (in mGy)

Radiograph	Projection	Present study (1998): median values	USA (1992) CRCPD/CDRH [19]: median values	NRPB (1986) [4]: median values	NRPB (1992) [15]	IAEA Basic Safety Standard (1996) [20]
Chest	PA	0.3	0.17	0.18	0.3	0.4
	LAT	1.2	—	0.99	1.5	1.5
Abdomen	AP	9.2	5.6	6.68	10	10
Pelvis/hip	AP	5.3	—	5.67	10	10
Skull	AP/PA	4.7	—	4.20	5	5
	LAT	3.0	1.6	2.19	3	3
Cervical spine	AP	0.7	1.5	—	—	—
	LAT	1.5	—	—	—	—
Thoracic spine	AP	6.4	—	—	7	7
	LAT	15.9	—	—	20	20
Lumbar spine	AP	9.1	6.4	7.68	10	10
	LAT	14.0	—	19.7	30	30

similar patients in different hospitals suggested that significant reductions in the dose from these exposures would be possible without adversely affecting image quality. The spread is mainly due to the choice of exposure factors, technique, focus-to-film distance, collimation, film–screen speed and the output of the X-ray machine used. This survey indicates that there is considerable scope for dose reduction for examinations of the skull, abdomen and lumbar and thoracic spine.

Reduction in ESD with increasing speed of the image receptor has been demonstrated in the UK [5, 23]. In the UK, the percentage of rooms with a mean speed greater than 200 rose from 23% for the 1986 NRPB survey [4] to nearly 80% for the 1996 UK survey [5]. This change to a faster film–screen combination was probably the main factor in reducing the ESD by 30–40% [5]. In this survey, only 10 out of 22 rooms (45%) used a speed class of 300–400 (based on manufacturers' data); all hospitals used blue-based films. All the chest radiography was carried out using a speed class of 400. We believe the use of lower speed class is the largest contributing factor for the higher ESD.

The optimal tube potential in chest radiography has received a considerable amount of discussion in the radiological literature [23, 24]. Generally, a wide range of exposure levels has been observed due to the large variety of radiographic techniques, processing conditions, and film–screen speeds. It has been estimated that increasing the tube potential from 60 kVp to 90 kVp will result in an ESD saving of 60% [23].

In this survey, only two out of the 12 hospitals used a high tube potential technique ($\geqslant 100$ kV) for chest radiography; only 18% of the patients surveyed. In a pilot research programme coordinated by the IAEA, conducted in seven developing countries, it was reported that only one out of 21 X-ray rooms dedicated to chest radiography used a high tube potential technique [7]. This explains why the ESD values measured were higher than the international reference values which were defined for high tube potential techniques. The CEC has recommended a technique of 125 kV [20]. The low tube potential technique will probably be employed for some time to come as radiologists prefer the higher contrast chest radiographs. Martin et al [25] found that increasing tube potentials by 8–13 kV in lumbar and thoracic spine examinations resulted in a dose reduction of 26–36%.

As pointed out earlier, reference doses are based on a standard-sized 70 kg man defined by ICRP 23 [26]. The 10 kg difference from our study would obviously affect the validity of adopting the reference doses without modification. As the dose increases with weight, one alternative is to adopt the dose–weight adjustment of about 2% per kg as recommended by Hart and Shrimpton [27]. Thus, the dose levels determined in this survey would have to be increased by 20% in order to be compared directly with the established international references doses.

Reference values described in the IAEA and CEC were determined on the basis of third quartile of patient dose distributions obtained in European surveys in recent years. This approach is consistent with the recommendations given in ICRP Publication 60 [28]. It is reasonable to establish a set of reference dose values for the average weight found in most Asian countries. This is also supported by a European study on dose comparison between groups of patients of various size and shape [29].

Effective dose is likely to become the standard measure for comparing risks from various sources of radiation exposure. The determination of effective dose is complex and depends on the Monte Carlo model used and the assumptions made [30]. The effective dose calculation is based on the assumption of an average 70 kg patient [17, 18], whereas in this study the mean patient weight is 60 kg. Thus the reported effective dose in this study should be regarded as an indicator only and caution is needed for intercomparison with values in Europe.

This national survey has led to an increased awareness amongst professionals in diagnostic radiology in Malaysia of the need for reduction in patient dose. Since the survey, faster film–screen combinations have been introduced in many hospitals and greater emphasis on quality assurance should improve performance [13, 14]. The practical implementation of this concern has been encouraged by the Malaysian Radiological Society's plan to incorporate this in the national quality assurance programme. Furthermore, the data will be used by the Atomic Energy Licensing Board for the formulation of a national guidance dose level for incorporation in the amendments of the 1988 Malaysia Radiation Protection Regulations (Basic Safety Standard).

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References

1. National Radiological Protection Board/Royal College of Radiologists. Patient dose reduction in diagnostic radiology. In: Documents of the NRPB. London: HMSO, 1990:1(3).
2. National Council on Radiation Protection and Measurements. Exposure of the US population from diagnostic medical radiation. Bethesda, Maryland, USA: NCRP, 1989.
3. Shrimpton PC, Wall BF, Jones DG, Fisher ES, Hillier MC, Kendall GM, et al. Doses to patients from routine diagnostic X-ray examinations in England. Br J Radiol 1986;59:749–58.
4. Shrimpton PC, Wall BF, Jones DG, Fisher ES, Hillier MC, Kendall GM, 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.
5. Hart D, Hillier MC, Wall BF, Shrimpton PC, Bungay D. Doses to patients from medical X-ray examinations in the UK—1995 review, NRPB-R289. London: HMSO, 1996.

6. Heggie JCP. A survey of doses to patients in large public hospitals resulting from common plain film radiographic procedures. Austral Phys Eng Sci Med 1990;13:71–80.
7. International Atomic Energy Agency/Commission of the European Communities. Radiation doses in diagnostic radiology and methods for dose reduction, IAEA-TECDOC-796, Brussels: CEC, 1995.
8. Ortiz P, Maccia C, Padovani R, Vano E, Carlsson GA, Schibilla H. 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.
9. United Nations Scientific Committee on the Effects of Atomic Radiation. 1988 Report to the General Assembly, with scientific annexes, United Nations Sales Publication E.88.IX.7. New York: UN, 1988.
10. United Nations Scientific Committee on the Effects of Atomic Radiation. Sources, effects and risks of ionizing radiation. Report to the General Assembly, with annexes. New York: UN, 1993:227.
11. Harrison RM, Clayton CB, Day MJ, Owen JP, York MF. A survey of radiation doses to patients in five common diagnostic examinations. Br J Radiol 1983;56:383–95.
12. Ng KH, Lee HP, Wang HB, Ruzman N, Samuel D. Patient dosimetry at the University Hospital of the University of Malaya. In: Ng KH, Bradley DA, editors Proceedings of Radiation and Occupational Health Symposium, 22–23 November 1993. Kuala Lumpur: Malaysian Institute of Physics, 1995:58–66.
13. Ng KH. Recent advances in patient dosimetry in diagnostic radiology. In: Tajuddin AA, Bradley DA, editors. Centennial of the X-ray—an account of developments in radiological physics and radiology in Malaya and Malaysia. Kuala Lumpur: Malaysian Institute of Physics, 1995:49–71.
14. Wang HB, Ng KH. Quality Assurance Programme in Radiology—the Malaysian experience. Phys Med Biol 1994; 39a/Part 1:305.
15. National Radiological Protection Board. National protocol for patient dose measurements in diagnostic radiology dosimetry. Report of a Working Party of the Institute of Physical Sciences in Medicine. Chilton: NRPB, 1992.
16. Gibson RS. Principles of nutritional assessment. New York: Oxford University Press, 1990:178–82.
17. LeHeron JC. XDOSE: A user's guide. Christchurch; New Zealand: National Radiation Laboratory, Ministry of Health, 1994.
18. Hart D, Jones DG, Wall BF. Normalized organ doses for medical X-ray examinations calculated using Monte Carlo techniques, NRPB-SR262. London: HMSO, 1994.
19. Council of Radiation Control Program Directors/ Center for Devices and Radiological Health. Average patient exposure/dose guides 1992, CRCPD Pub 92–4. Frankfurt: CRCPD, 1992.
20. International Atomic Energy Agency. International Basic Safety Standards for Protection Against Ionising Radiation and for the Safety of Radiation Sources. Safety series no. 115-1. Vienna: IAEA, 1996.
21. Wall BF, Shrimpton PC. Patient dose protocols and trends in the UK. Radiat Prot Dosim 1995; 57:359–62.
22. EUR16260 EN. European guidelines on quality criteria for diagnostic radiographic images, EC DGXII, 1996.
23. Warren-Forward HM, Millar JS. Optimization of radiographic technique for chest radiography. Br J Radiol 1995;68:1221–9.
24. Buttler PF, Conway BJ, Suleiman OH, Koustenis GH, Showalter CK. Chest radiography: A survey of techniques and exposure levels currently used. Radiology 1985;156:533–6.
25. Martin CJ, Darragh CL, McKenzie GA, Bayliss AP. Implementation of a programme for reduction of radiographic doses and results achieved through increases in tube potential. Br J Radiol 1993; 66:228–33.
26. International Commission on Radiological Protection. Report of the Task Group on Reference Man, ICRP 23. Oxford: Pergamon Press, 1975.
27. Hart D, Shrimpton PC. The significance of patient weight when comparing X-ray room performance against guideline levels of dose. Br J Radiol 1991;64:771–2.
28. International Commission on Radiological Protection. 1990 Recommendations of the International Commission on Radiological Protection, ICRP 60. Oxford: Pergamon Press, 1991.
29. Lindskoug BA. The Reference Man in diagnostic radiology dosimetry. Br J Radiol 1992;65:431–7.
30. Hart D, Jones DG, Wall BF. Estimation of effective dose in diagnostic radiology from entrance surface dose and dose–area product measurements, NRPB-R262. London: HMSO, 1994.