Radiation Exposure of the UK Population from Medical and Dental X-ray Examinations

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ABSTRACT

Knowledge of recent trends in the radiation doses from x-ray examinations and their distribution for the UK population provides useful guidance on where best to concentrate efforts on patient dose reduction in order to optimise the protection of the population in a cost-effective manner. In this report, the results of a recent survey of the frequency of medical and dental x-ray examinations in the UK and contemporary data on the radiation doses typically received by patients, are used to assess trends in the extent and the pattern of the population exposure. Individual patient doses, expressed in terms of the effective dose, range from a few microsieverts for simple radiographic examinations of the teeth, limbs or chest to tens of millisieverts for prolonged fluoroscopic procedures or some computed tomography (CT) examinations. A total of about 41.5 million medical and dental x-ray examinations are now conducted each year in the UK (0.70 examination per head of population) resulting in an annual per caput effective dose of 330 μSv. This is not significantly different from the previous rough estimate of 350 μSv for 1991. However, over the last ten years CT has more than doubled its contribution and is now responsible for 40% of the total dose to the population from medical x-rays. In contrast, the contribution from conventional radiographic and fluoroscopic examinations has nearly halved to about 44%. Interventional and angiographic procedures together contribute the remaining 16%. The annual per caput dose of 330 μSv is low in comparison with other countries having similarly developed systems of healthcare. This is due to both a lower frequency of x-ray examinations per head of population and generally lower doses in the UK than in other developed countries. However, the much increased contributions of CT, angiography and interventional procedures to the UK population dose indicate an urgent need to develop radiation protection and optimisation activities for these high dose procedures to the same level as has been achieved for conventional radiology.

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CONTENTS

1 INTRODUCTION

The population of the UK is exposed to ionising radiation from a number of natural and man-made sources, but by far the largest artificial source is medical radiology. Since their discovery at the turn of the last century, the use of x-rays to see inside the body, without recourse to more invasive techniques, has been of enormous benefit in the safe and effective diagnosis of a multitude of diseases and injuries. Medical imaging technology has evolved rapidly, particularly over the last 30 years, to the stage where, today, detailed three-dimensional images of many parts of the body can be obtained in a few minutes and minimally invasive surgical procedures are conducted under fluoroscopic control. The radiation doses delivered to the patient by some of these sophisticated procedures are considerable but so are the benefits, particularly when they allow alternative and more hazardous diagnostic or therapeutic techniques to be avoided. In contrast, the radiation doses associated with the majority of routine x-ray examinations involving conventional radiography and fluoroscopy have gradually come down. Not only has the technology developed and the sensitivity of imaging devices increased, but, in recent years, radiation protection has received increasing attention in diagnostic radiology in the UK. With patient dose monitoring and audit procedures becoming widely practised, practitioners are adopting more dose-efficient procedures, and manufacturers are introducing an increasing number of dose-saving features into x-ray imaging equipment.

One way of assessing the impact of these changes in diagnostic radiology practice on the radiation exposure of the population and the potential health detriment is to monitor trends in the annual per caput effective dose. Although medical exposures are not distributed uniformly around the population, the annual per caput dose provides a better indication of overall trends in individual doses as radiology practice changes, than the annual collective dose, which is also influenced by changes in the number of people in the population. Per caput dose estimates provide useful information on the relative contribution of different sources of ionising radiation to the population dose. They can be used to compare the contribution from diagnostic radiology with those from natural or other artificial sources of radiation and to see how the contributions differ between different countries or regions. More specifically for this report, they allow comparison of the contributions from different types of x-ray examination or from different medical imaging modalities in the UK. Such information provides guidance on where best to concentrate efforts on dose reduction, so as to optimise the protection of the public in the most cost-effective manner.

However, it should be remembered that the relationship between effective dose and the probability of delayed radiation effects is critically dependent on the age distribution of the exposed population. The age distribution of patients undergoing x-ray examination is generally skewed towards the elderly, for whom the lifetime risks of radiation-induced cancer are much reduced compared to the

general population. Care is consequently needed if per caput or collective dose estimates for medical exposures are to be related to radiation detriment or if comparisons are made between such doses estimated for populations with significantly different age structures.

Recent estimates by NRPB[1] have put the contribution from patients undergoing x-ray examinations at nearly 90% of the total per caput effective dose from all artificial sources in the UK, with diagnostic nuclear medicine procedures contributing a further 8% (radiotherapy exposures are deliberately excluded from this analysis). In contrast, all occupational and public exposures arising inadvertently from medical and other uses of ionising radiation, including the UK nuclear power programme, amount to less than 3% of the total. Consideration of the different age distributions of those medically, occupationally and publicly exposed would reduce the potential collective health detriment for the medically exposed by about a factor of two compared to the other two population groups[2].

Being the largest man-made contributor to the per caput dose is, however, not necessarily a bad thing. A vital feature of medical exposures is the direct benefit they provide to the healthcare of the exposed individual; an advantage which is seldom, if ever, associated with occupational or public exposures. Medical exposures should be justified on an individual basis by offsetting the very small radiation risks for patients with the usually very substantial benefits from improved diagnosis leading to more effective treatment of their medical problem. A large per caput dose will be justified if all the individual medical exposures are justified (and optimised). Better healthcare for the population might well be achieved by increasing the per caput dose, particularly if healthcare resources have been restrained for other reasons.

NRPB has previously estimated per caput and collective doses from medical x-rays in 1986 and 1991. Both these earlier estimates were made in terms of the quantity ‘effective dose equivalent’, the precursor to ‘effective dose’ which was based on radiation risk coefficients for a more limited set of organs and tissues[3]. For the partial body exposures involved in diagnostic radiology, the relationship between effective dose and effective dose equivalent varies, depending on which organs or tissues are close to the x-ray beam. For most examinations of the trunk the effective dose lies within ±20% of the effective dose equivalent, whereas for examinations of the head effective doses tend to be lower than corresponding effective dose equivalents by about a factor of two[4]. The per caput effective dose equivalent in Great Britain in 1986 from all types of medical and dental x-ray examination, was estimated at about 290 μSv (collective dose 16,000 man Sv)[5]. A survey of CT practice in the UK in 1989[6] found that there had been rapid growth in the use of CT, resulting in a per caput effective dose equivalent from CT alone of 78 μSv for the UK in that year (collective dose 4500 man Sv)[7]. The per caput effective dose equivalent for all diagnostic radiology was therefore amended to about 350 μSv for the UK in 1991 (collective dose 20,000 man Sv) assuming that the contribution from conventional radiology had remained more or less constant[8].

A 1995 review of doses from common radiographic and fluoroscopic x-ray examinations held on a National Patient Dose Database by NRPB indicated that there had been on average a 30% reduction in entrance surface dose (ESD) and dose–area product (DAP) measurements over the previous ten year period[9]. This was estimated to lead to a substantial fall in the collective effective dose (about 4700 man Sv), assuming the number of such examinations had remained constant. A contrary trend in the collective dose was predicted for CT examinations, since the number of CT scanners in the UK was still rising in 1991 and did not reach a plateau until 1995. On the basis of this increase in availability, it was estimated that CT comprised about 4% of all x-ray examinations by 1995 and could be contributing up to about 40% of the collective dose[10]. However, without more reliable data on the exact numbers of CT and conventional x-ray examinations carried out, it was difficult to predict the direction of any change in the overall per caput or collective dose. Consequently, for the 1999 NRPB review of the radiation exposure of the UK population[1], it was assumed that the contribution from medical x-rays remained unchanged at an annual per caput effective dose of 350 µSv. A recent NRPB survey of the frequency of all types of x-ray examination in the UK[11] has now provided the necessary information to make a more reliable estimate.

2 METHOD

To estimate the annual UK per caput effective dose from all medical and dental x-ray examinations, information is required on the annual frequency and the mean effective dose for each type of examination. A recent NRPB survey of the frequency of x-ray examinations in the UK in 1997/98 has been used to provide the information on the annual numbers of x-ray examinations[11], as discussed in Section 2.1. Estimates of the mean effective dose for each examination were obtained from a number of sources, the predominant one being the National Patient Dose Database maintained by NRPB[9]. This contains data collected in the period from 1988 to 2000 covering about 60 types of radiograph and 100 types of x-ray examination. For other types of examination and when the information held on the National Patient Dose Database was found to be inadequate to derive reliable effective doses, recourse has been made to the published literature, as discussed in Section 2.2.

2.1 Estimation of x-ray examination frequencies

The NRPB x-ray examination frequency survey[11] was based on data gathered from two geographically separate English NHS regions (Trent and South Thames) in the financial year 1997/98. A sample of 38 out of the 65 NHS trusts in these regions sent details on the number of medical x-ray examinations of different types that they had performed in the year, as recorded in their computerised

radiology information systems. Whereas 58% of the trusts in the two regions were sampled in the NRPB survey, the sample was biased towards larger trusts so that 68% of all x-ray examinations in the two regions were covered, amounting to 16% of all x-ray examinations in England. Despite an occasionally confusing mixture of terminology adopted by the trusts for describing the different types of x-ray examination, 99% of the data was finally allocated to 150 distinct and identifiable types of examination. The survey data was extrapolated to the whole of the English NHS using annual statistics on the total numbers of all types of x-ray examination provided to the Department of Health by NHS trusts (known as KH12 returns). Additional data from Wales, Northern Ireland and Scotland were used to estimate x-ray examination frequencies in NHS hospitals in these countries and thus to extend the analysis to the whole of the UK.

Information was also gathered on the annual numbers of x-ray examinations conducted in general dental practice, independent hospitals, mammography screening, Ministry of Defence hospitals and medical units, prisons, and chiropractic clinics, to cover all radiology practice performed outside the NHS. For the purposes of this report, these numbers were added to the NHS numbers for the corresponding types of examination, to provide the total numbers for each of the 150 types of examination, performed both inside and outside the NHS.

2.2 Estimation of typical effective doses

A typical effective dose was attributed to each one of the 150 distinct and identifiable types of x-ray examination found in the frequency survey, as listed in the appendix. To do this, estimates of the mean effective dose for each examination were obtained from a number of sources, the predominant one being the National Patient Dose Database[9].

Doses are recorded in the National Patient Dose Database as entrance surface dose (ESD) values for individual radiographs and dose–area product (DAP) values for complete examinations. The ‘typical’ dose for a specific radiograph or examination was taken to be the mean of the doses recorded in the National Patient Dose Database over the whole of the 1990s. Data for the whole decade were used in order to get a sufficient sample size, even for the less common examinations. The mean dose for each examination was derived by firstly calculating the mean dose for the sample of patients measured in each radiology room and then taking the mean of these room mean values. In this way equal weight was given to each radiology room in the National Patient Dose Database.

NRPB-R262[12] contains generalised conversion coefficients, in Tables 16, 17 and 18, for estimating effective dose from ESD and DAP measurements, assuming that the x-ray spectra (tube voltage and total filtration) used are close to the average. Typical effective doses were derived from the mean ESD or DAP values using these generalised conversion coefficients. For examinations consisting purely of radiographs, the typical effective doses from each radiograph were

added to provide a typical effective dose for the complete examination. A small survey of practice at ten hospitals was undertaken to determine the types and number of projections typically used for the common radiographic examinations. The results are shown in Table 1. For skull examinations further information on typical projections was obtained from Gallagher[13].

For some radiographs and examinations, a conversion coefficient was not directly available from NRPB-R262. Table 2 indicates how suitable conversion coefficients were estimated for five additional examinations (including 'extremities') and four additional radiographs, by comparison with existing conversion coefficients for similar examinations. The very approximate conversion coefficients for extremities were used to estimate effective doses for 15 examinations of different parts of the arms and legs. The effective doses for these examinations are all very small, and they contribute less than 0.05% of the total collective dose. Thus any error in the total arising from the approximate nature of the conversion coefficients will be small.

A typical effective dose estimate, derived from data in the National Patient Dose Database and conversion coefficients in NRPB-R262 or Table 2, was obtained for 90 examinations out of the 150. The information on ESD, DAP, conversion coefficients and effective doses was recorded on a spreadsheet. The number of dose measurements on which the effective dose value was based and the number of hospitals which had supplied measurements were also recorded. This information gave some indication of how representative the estimate of effective dose was for national practice.

Dose data from other published surveys were also added to the spreadsheet for types of examination not adequately included in the National Patient Dose Database. These included CT examinations, doses for five of which were taken from the NRPB survey completed in 1991[7], and two were from a Welsh CT

TABLE 1 Typical projections for solely radiographic examinations

	Projection		
Examination	AP	PA	LAT
Skull*	0.75	1	1
Cervical spine	1	–	1
Thoracic spine	1	–	1
Lumbar spine	1	–	1
Hip	1	–	0.5
Femur	1	–	1
Ankle	1	–	1
Knee	1	–	1
Chest	–	1	–
Pelvis	1	–	–
Abdomen	1	–	–

*Derived from Gallagher[13].

TABLE 2 Derivation of non-standard conversion coefficients

Examination	E/ESD (mSv/mGy)	E/DAP [mSv/(Gy cm^z)]	Comments
Arthrography	–	0.1	Average of hip AP and shoulder AP
Extremities (15 exams of arms and legs)	0.005	0.01	Chosen to be substantially less than the lowest values in NRPB-R262 (skull and lateral cervical spine)
Hip lateral	0.06	–	Same as hip AP
Lymphangiography		0.2	Typical of trunk
Shoulder lateral	0.007	–	Same as shoulder AP
Skeletal survey	–	0.1	Average of arms, legs, skull LAT, lumbar spine LAT, chest AP, abdomen/pelvis AP
Venography (limb)	–	0.1	Average of leg and abdomen AP
Whole spine/scoliosis			
AP/PA	0.1	–	Average of thoracic and lumbar spine AP
LAT	0.025	–	Average of thoracic and lumbar spine LAT

survey performed in 1994[14]. Only data from outside the UK were available for the less common CT examinations, thus CT angiography and CT bone mineral densitometry doses were taken from surveys in Germany and the USA, respectively. In all, published surveys provided mean effective dose estimates for 25 further examinations. Where there was more than one published survey with a mean effective dose for an examination conducted in the UK, a weighted mean of the mean effective doses was taken (ie weighted by the sample size). If there were no published effective dose estimates for the UK the mean of the mean effective doses for foreign countries weighted by sample size was taken. If there was only one effective dose estimate for the UK and more than one foreign estimate, the weighted mean of all relevant data was taken, unless the UK sample was much larger than the samples from abroad, in which case the UK data alone were used. Finally, when no dose data could be found for a specific examination, an approximate estimate of the effective dose was made by comparison with similar examinations. For example, doses for CT extremity examinations and CT interventional procedures were estimated by comparison with other CT examinations. Such comparative dose estimates covered the remaining 35 examinations.

The effective dose estimates were checked for consistency between similar examinations – for instance, that the dose for an x-ray of the hand was similar to that for the wrist. Only two adjustments were made as a result of this consistency check; the dose for the ‘radius and ulna’ was lowered to match that for the elbow, and the dose for the ‘tibia and fibula’ was raised to match that for the ankle. The data for the elbow and the ankle were based on larger samples than those for the ‘radius and ulna’ and ‘tibia and fibula’.

The effective doses for mammography were derived from the mean glandular dose by multiplying by a tissue weighting factor for women of 0.1, being twice the average value for both sexes of 0.05 recommended by ICRP. Mammographic

doses were estimated separately for three cases: screening, recall and symptomatic examinations. In the NHS Breast Screening Programme[15], women who are screened for the first time have two radiographic views taken of each breast, oblique and cranio-caudal. It is usually current practice for women who are screened on subsequent occasions to have just one view taken of each breast. Effective doses and the corresponding collective dose were estimated separately for these two groups. Those women who are recalled for further assessment after being screened have, on average, 2.5 films taken[16], and their effective dose was estimated as being in proportion to routine screening examinations, ie 2.5/4 of the dose for a two view per breast examination. Symptomatic women are those referred directly to a hospital x-ray department by their GP or consultant, after suspicious changes have been detected in their breasts. They usually have two radiographic views taken of each breast, so the effective dose for their examination was taken to be the same as that for women being screened for the first time.

Some examinations were not sufficiently well specified for estimation of even an approximate effective dose. For example, there were 3000 procedures that were simply called 'interventional', with no more specific information given. To assign an effective dose to these, the average of the doses for all the other 240,000 interventional procedures was taken. A similar approach was followed for the 4000 CT examinations (out of well over a million) that did not fit into one of the 11 types that were clearly defined. The 300,000 conventional examinations (0.7% of the total) that could not be properly identified were labelled 'unassignable'. Two-thirds of these involved fluoroscopy at an unspecified anatomical location, and the other third involved foreign body demonstration. Those that involved fluoroscopy were assigned the mean effective dose (3 mSv) for the following fluoroscopic examinations: barium swallow, barium meal, barium follow-through, barium enema and MCU. Those that involved foreign body demonstration were assumed to consist of a couple of radiographs and were therefore assigned a dose of 0.4 mSv being twice the average effective dose for the following radiographs commonly used in such procedures: abdomen AP, chest AP, skull AP and soft tissues of the neck (lateral).

3 RESULTS

3.1 Collective and per caput doses

The appendix lists the data used to estimate the annual collective effective dose for each type of x-ray examination. X-ray examinations are listed in the same manner as in the NRPB frequency survey[11], ie the following order: 'head and neck', spine, 'limbs and joints', chest, angiography, gastrointestinal tract, biliary system, urinary system, gynaecology and other infrequent examinations, CT, and interventional procedures. The information itemised for each type of examination includes the following.

a total number of examinations performed in 1997/98 for all sectors of healthcare in the UK,
b typical ESD and appropriate E/ESD conversion coefficient,
c typical DAP and appropriate E/DAP conversion coefficient,
d typical effective dose,
e source of data for this effective dose,
f number of patients sampled in this source,
g number of hospitals sampled in this source,
h reliability rating (explained in Section 3.2),
i collective dose for the UK in man Sv,
j % contribution to the total collective dose.

The source of information for the dose data is indicated either by a numbered reference, or by NPDD (meaning the National Patient Dose Database), or by naming the analogous examination(s) from which data have been used. Where more than one effective dose estimate is available for the same examination, the chosen value has been placed uppermost in the appendix. A reasonable similarity was found for most of the cases where the effective dose for a complete examination could be calculated from both the ESD/projection and the DAP/examination.

To give an example of the effective dose calculations, skull examinations were assumed (following Gallagher[13], and as shown in Table 1) to consist on average of one PA radiograph, one lateral radiograph and 0.75 of an AP radiograph (ie carried out in 75% of cases). The mean ESDs for these in the National Patient Dose Database were 2.5, 1.4 and 1.9 mGy, respectively. Using the respective conversion coefficients of 0.008, 0.009 and 0.012 mSv/mGy for each projection (from NRPB-R262) results in a total effective dose of 0.06 mSv. For complete examinations of the skull, the mean DAP in the National Patient Dose Database was 1.46 Gy cm^2 and the weighted mean conversion coefficient for the three projections from NRPB-R262 was 0.028 mSv/(Gy cm^2), so the estimated total effective dose was 0.04 mSv. Since the latter estimate was based on a much smaller sample, the former value of 0.06 mSv was used as the typical effective dose for this examination.

For each of the 150 x-ray examinations, the annual number performed in the UK and the estimated typical effective dose were multiplied together to provide an annual collective dose estimate for each examination. Absolute and percentage values are shown in the last two columns of the appendix.

To summarise this information, in Table 3 these 150 examinations have been combined into just 63 categories, each containing similar types of examination. These categories are similar to those used in NRPB-R320 (they are shown in bold type in the first column of the appendix), except that all angiographic examinations have been grouped together after the other radiographic and fluoroscopic examinations. The collective dose for each of the categories and sub-totals for all ‘conventional’, all angiographic, all CT and all interventional procedures, are shown in Table 3. The total annual collective dose from all x-ray examinations in the UK is also shown at the bottom of the table and amounts to

19,300 man Sv. With a UK population of 59 million in 1997, this implies an annual per caput effective dose of 330 μSv. The data in Table 3 cover diagnostic and interventional radiology practice from all sectors of healthcare in the UK, including NHS, independent and military hospitals, dental and chiropractic practices, and mammography screening.

Table 3 also shows the percentage contribution of each examination category to the total number of all types of medical and dental x-ray examinations and to the total collective (or per caput) dose. CT examinations represent just over 3% of all medical and dental x-ray examinations (5% of all examinations performed in NHS hospitals) but, as in the previous NRPB estimate[10], are responsible for 40% of the collective dose. All the angiographic procedures taken together are responsible for about 10% of the collective dose, and all interventional radiology procedures for about 6%. The biggest contribution to collective dose from any single examination is from CT of the abdomen, which is responsible for 15%. Barium enema examination of the colon is the next highest, contributing about 13%. All other barium studies are much less significant, contributing only 3% in total.

Figure 1 shows the percentage contribution to UK collective dose and frequency from the fifteen examinations that make the biggest contribution to collective dose. The examinations are arranged in descending order of their contribution to collective dose. The relatively high dose CT examinations, barium enemas and cardiac angiography procedures occupy the top six places. The next five are taken by moderate dose radiographic procedures that are relatively common, such as those of the lumbar spine, mammography and intravenous urograms (IVUs), whereas the last four are either high dose and low frequency, such as PTCAs, or moderate dose and moderate frequency, such as hip examinations. Nine of these fifteen examinations are relatively infrequent, contributing less than 1% each to the total number of x-ray examinations in the UK.

It can be seen from Table 3 that the most frequent examination is dental radiography. Although about half a million dental x-ray examinations are performed in NHS hospitals each year, 25 times as many (12.5 million) are conducted by dentists in primary care dental practice. This makes dentists responsible for 30% of all medical and dental x-ray examinations[11]. However, the very low effective doses associated with dental radiography (typically 5 μSv for an intraoral examination[17] and 10 μSv for a panoramic examination[18]) result in a collective dose of only 77 man Sv and a per caput dose of only 1.3 μSv from primary care dental practice. This represents only about 0.4% of the total collective dose or the per caput dose from all x-ray examinations.

Figure 2 shows the contribution to UK collective dose and frequency from the 15 most frequently performed x-ray examinations. The examinations are arranged in descending order of their frequency. It can easily be seen that some of the most common examinations (chest, dental and limbs) make very small contributions to collective dose. Indeed, the contributions to collective dose from examinations of the limbs are so small that they are hardly visible in the diagram.

TABLE 3 UK annual frequencies and collective doses by examination category

Examination category	Number of examinations	Percentage frequency	Collective dose (man Sv)	Percentage collective dose
Conventional radiology				
Skull and facial bones	1,046,830	2.52	39.9	0.21
Head – soft tissue	70,784	0.17	2.2	0.01
Teeth – intraoral (hospital)	177,086	0.43	0.9	0.00
Teeth – panoramic (hospital)	392,853	0.95	3.9	0.02
Teeth – intraoral (dentists)	9,562,500	23.02	47.8	0.25
Teeth – panoramic (dentists)	2,937,500	7.07	29.4	0.15
Neck – soft tissue	40,319	0.10	0.2	0.00
Cervical spine	858,547	2.07	60.1	0.31
Thoracic spine	281,215	0.68	196.9	1.02
Lumbar spine	824,763	1.99	824.8	4.27
Lumbo-sacral joint	338,901	0.82	92.2	0.48
Whole spine/scoliosis	33,614	0.08	3.4	0.02
Myelography	4,826	0.01	9.8	0.05
Shoulder girdle	775,553	1.87	8.3	0.04
Upper arm	138,912	0.33	0.1	0.00
Elbow	435,202	1.05	0.4	0.00
Forearm, wrist and hand	2,960,214	7.13	1.6	0.01
Pelvis	919,740	2.21	643.8	3.34
Hip	885,489	2.13	321.2	1.66
Femur	191,294	0.46	0.5	0.00
Leg length	16,844	0.04	3.1	0.02
Knee, lower leg, ankle and foot	4,123,461	9.93	7.2	0.04
Arthrography	8,752	0.02	1.5	0.01
Skeletal survey	12,032	0.03	21.7	0.11
Chest	8,286,520	19.95	165.8	0.86
Mammography	1,726,303	4.16	466.3	2.42
Abdomen (plain film)	1,217,192	2.93	852.0	4.42
Oesophagus	123,751	0.30	185.6	0.96
Stomach and duodenum	98,581	0.24	256.3	1.33
Small intestine	41,089	0.10	154.2	0.80
Colon	359,436	0.87	2,587.9	13.41
Other abdominal investigations	11,753	0.03	35.7	0.19
Biliary system	67,627	0.16	270.3	1.40
Kidneys and ureters	14,731	0.04	29.0	0.15
IVU	162,502	0.39	390.0	2.02
Bladder and urethra	82,941	0.20	102.5	0.53
Gynaecology	27,627	0.07	29.9	0.15
Lymphangiography	128	0.00	0.0	0.00
Tomography other than of teeth	2,722	0.01	0.4	0.00
Bone mineral densitometry	27,265	0.07	0.1	0.00
Sub-total (conventional radiology)	**39,287,402**	**94.6**	**7,847**	**40.7**

TABLE 3 ***(continued)***

Examination category	Number of examinations	Percentage frequency	Collective dose (man Sv)	Percentage collective dose
Angiography				
Cerebral angiography	11,999	0.03	48.0	0.25
Pulmonary angiography	5,529	0.01	29.9	0.16
Abdominal angiography	12,711	0.03	285.0	1.48
Aortography	11,161	0.03	122.6	0.64
Angiocardiography	162,871	0.39	1076.4	5.58
Peripheral angiography	116,903	0.28	361.5	1.87
Sub-total (angiography)	**321,174**	**0.8**	**1,923**	**10.0**
Computed tomography				
CT head	618,391	1.49	1236.8	6.41
CT neck	24,332	0.06	60.8	0.32
CT abdomen	297,244	0.72	2972.4	15.40
CT chest	192,885	0.46	1543.1	8.00
CT pelvis	139,722	0.34	1397.2	7.24
CT extremity	18,401	0.04	9.2	0.05
CT spine	63,183	0.15	252.7	1.31
CT pelvimetry	8,200	0.02	1.6	0.01
CT interventional	13,184	0.03	131.8	0.68
CT bone mineral densitometry	1,594	0.00	1.6	0.01
CT angiography	5,129	0.01	30.8	0.16
CT other	4,771	0.01	23.9	0.12
Sub-total (CT)	**1,387,036**	**3.3**	**7,662**	**39.7**
Interventional radiology				
Biopsy	28,202	0.07	43.6	0.23
Biliary and urinary systems	47,968	0.12	235.1	1.22
Cardiovascular	121,810	0.29	903.9	4.68
Gastrointestinal	46,121	0.11	28.3	0.15
Other interventional	3,173	0.01	28.6	0.15
Sub-total (interventional radiology)	**247,274**	**0.6**	**1,239**	**6.4**
Unassignable examinations	**298,113**	**0.7**	**626.0**	**3.2**
Overall total	**41,541,000**	**100**	**19,298**	**100**

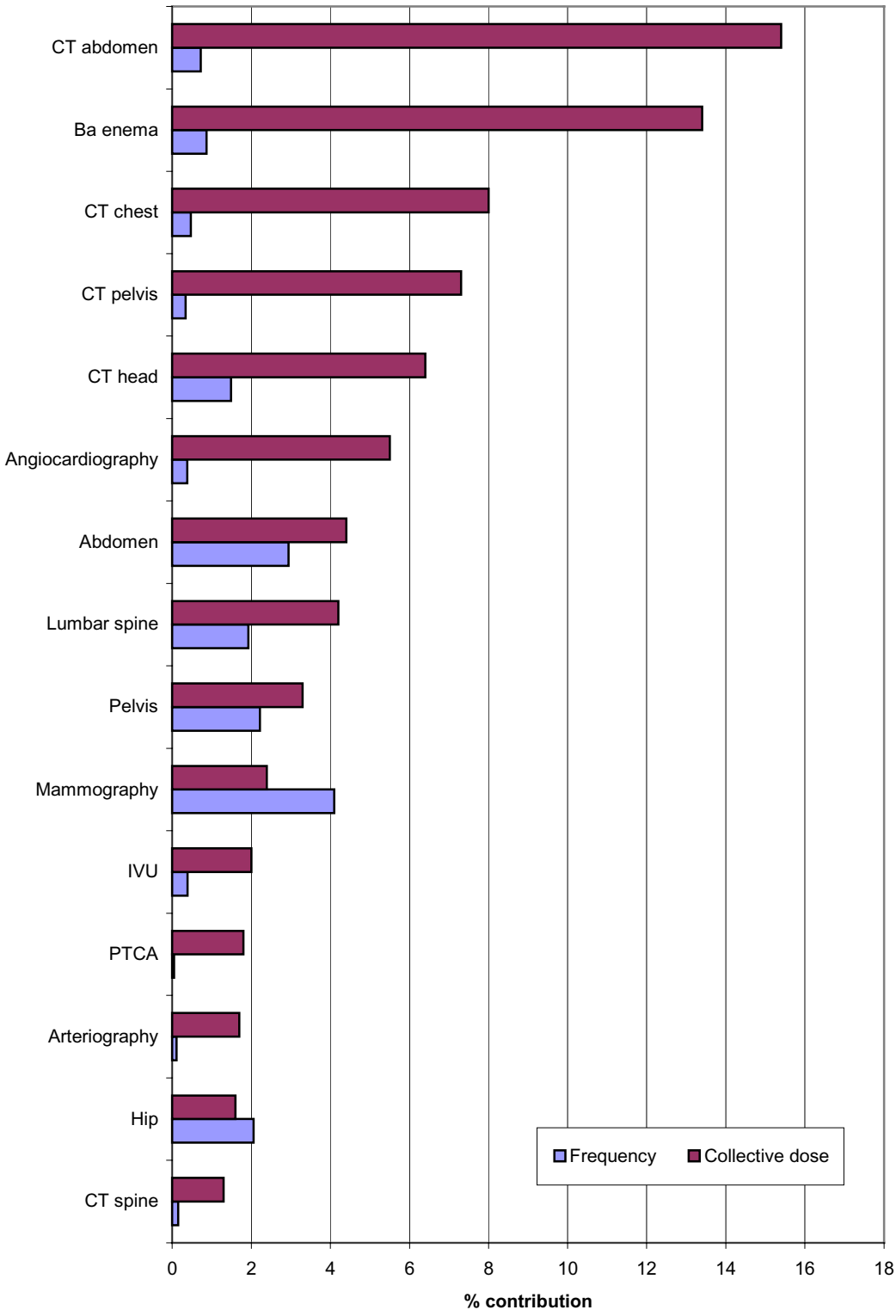

FIGURE 1 Contribution to UK collective dose and frequency from the 15 medical and dental x-ray examinations making the biggest contributions to collective dose

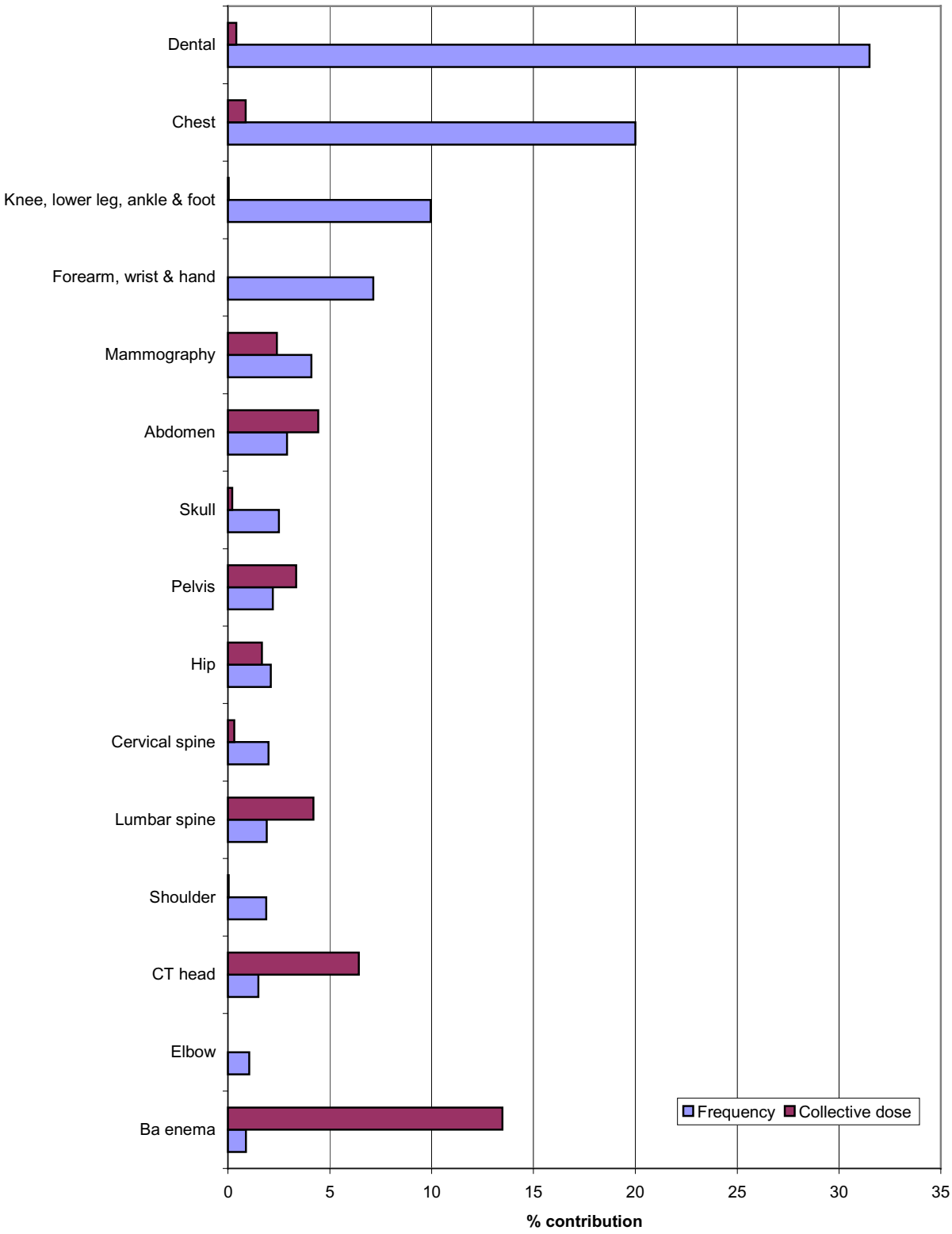

FIGURE 2 Contribution to UK collective dose and frequency from the 15 most frequent medical and dental x-ray examinations

3.2 Uncertainties

The uncertainty in the estimate of the total collective dose from all x-ray examinations in the UK is a combination of the uncertainties in the estimates of the frequency and the effective dose for each of the 150 types of examination studied in this report.

The statistical and systematic uncertainties in the estimates of the frequency for each type of examination are given in NRPB-R320[11] (Tables E1 and E2, respectively). They are expressed in terms of the absolute and percentage standard errors for each of the 63 categories of examination shown in Table 3.

A reliability scale was devised to give an approximate indication of the levels of uncertainty involved in the estimates of the typical effective doses for each examination. The scale comprises five levels of reliability (A to E), defined according to the quantity and quality of the data available for estimating typical effective doses, as shown in Table 4. For example, examinations fall into reliability level A when dose data are obtained from at least 100 UK hospitals and appropriate effective dose conversion coefficients are available directly from NRPB-R262[12], or NRPB-R250[19] if they are CT examinations. Levels B and C correspond to progressively less extensive, and hence less representative, sources of UK data. Dose data originating solely from foreign countries are given a reliability rating of D, no matter how extensive, because such data may not be completely representative of practices in the UK.

All of the 150 examination types were allocated to a reliability level, as shown in the appendix. Conventional x-ray examinations of the skull, lumbar spine, lumbo-sacral joint (LSJ), pelvis, chest, and abdomen are in level A because their typical effective doses were based on data from more than 100 UK hospitals in the National Patient Dose Database and appropriate conversion coefficients were available in NRPB-R262[12]. The more common CT examinations are also in level A because their typical effective doses, estimated in NRPB-R249[7], were based on practice observed at 126 UK hospitals using appropriate conversion coefficients from NRPB-R250[19].

TABLE 4 Reliability scale for the typical effective dose estimates

Reliability rating	Criteria	Approximate uncertainty
A	> 100 UK hospitals providing dose data Conversion factors available directly from NRPB-R262	±10%
B	>20 UK hospitals Conversion factors available directly from NRPB-R262	±25%
C	1–19 UK hospitals Conversion factors can be confidently derived from NRPB-R262	±50%
D	1–19 UK hospitals OR foreign data <20 patient measurements Conversion factors 'guesstimated'	Factor of 2
E	No dose measurement; estimated from other examinations	Factor of 3

Approximate ranges of uncertainty (shown in the last column of Table 4) have been attributed to each reliability level based on the dose distributions observed in the National Patient Dose Database. Table 5 shows the random uncertainties for examinations in reliability levels A, B and C derived from the standard errors on the means of the hospital mean dose values. In addition to these random uncertainties in the measured doses there is also a systematic uncertainty associated with the conversion coefficients used to calculate effective dose. These are difficult to predict but to make some allowance for them, a total uncertainty has been allocated for reliability ratings A, B and C (see the last column of Table 4) of about twice the average random uncertainty on the dose measurements (see Table 5). The effective dose estimates for examinations in reliability levels D and E are likely to be even more uncertain, and this has been recognised by giving them the (somewhat arbitrary) uncertainty ranges of a factor of two and three, respectively, shown in Table 4.

Table 6 shows that about half of the total collective dose estimated for the UK is due to examinations with reliability rating A. A further 20% is due to examinations rated B. Thus a substantial part of the collective dose is known to a reasonable accuracy.

To combine the uncertainties on the typical effective doses for each of the 150 types of examination with the uncertainties on the frequencies of the 63 examination categories, it was assumed that each type of examination had the same percentage uncertainty on frequency as the category it was in. For those 34 categories that consist solely of one examination (eg CT examinations), this is exactly correct. For those 29 categories that consist of more than one examination, it is an approximation. However, the uncertainty on frequency typically ranges from about 2% to 30%, while the uncertainty on typical effective dose ranges from 10% to 200%, so the uncertainty on the collective dose is generally dominated by the uncertainty on typical effective dose. The above approximation in the estimate of the frequency uncertainties will therefore have only a small impact on the estimate of the uncertainty on the collective dose.

Since the collective dose for each examination is the product of the frequency and the effective dose, the uncertainty on the collective dose for each examination was calculated by combining the relative (percentage) uncertainties for the frequency and for the effective dose using equation 1[20].

$$[U_R(CD_N)]^2 = [U_R(F_N)]^2 + [U_R(E_N)]^2 \quad (1)$$

where $U_R(CD_N)$ is the relative uncertainty on the collective dose for examination N, and the other two terms are the relative uncertainties for the frequency and the effective dose for that examination.

Since the total collective dose is the sum of the collective doses for each examination, the uncertainty on the total collective dose was calculated by combining the absolute uncertainties for the collective doses for each examination using equation 2[20].

$$[U_A(CD)]^2 = [U_A(CD_1)]^2 + [U_A(CD_2)]^2 + \ldots + [U_A(CD_N)]^2 \quad (2)$$

where $U_A(CD)$ is the absolute uncertainty on the total collective dose, $U_A(CD_1)$ is the absolute uncertainty on the collective dose for examination 1, etc.

This resulted in a calculated uncertainty on the total collective dose of about ±1700 man Sv, ie about ±9% of the total collective dose of 19,300 man Sv. The uncertainty on the corresponding per caput dose (330 µSv) will also be ±9% (ie ±30 µSv). This is less than the uncertainty on the best known effective doses (reliability A = 10%) because in adding together many individual collective doses the random uncertainties in each one tend to cancel each other out.

TABLE 5 Random uncertainties in dose values as function of reliability rating

Examination	Number of hospitals	Mean ESD (mGy) or mean DAP (Gy cm^2)	Standard deviation on mean	Standard error on mean	Random uncertainty (% SEOM)
A Reliability		Mean ESD			
Abdomen AP	302	5.4	3.1	0.18	3.3
Chest PA	373	0.16	0.14	0.0072	4.5
Pelvis AP	285	4.2	2.8	0.17	4.0
Lumbar spine AP	286	5.9	4.5	0.27	4.5
Lumbar spine LAT	363	14.0	9.7	0.51	3.6
LSJ	222	28.1	19.3	1.3	4.6
Skull LAT	123	1.35	0.9	0.08	6.0
					4.4 average
B Reliability		Mean ESD			
Hip AP	20	2.7	2.14	0.48	17.7
Knee AP	27	0.29	0.17	0.03	11.3
Thoracic spine AP	79	3.9	3.4	0.38	9.7
Thoracic spine LAT	75	10.8	10.6	1.22	11.3
		Mean DAP			
Ba swallow	54	9.98	14.1	1.91	19.2
Ba meal	89	11.4	12.0	1.27	11.1
Ba enema	87	26.5	24.4	2.62	9.9
Ba follow	29	13.4	11.5	2.14	15.9
IVP	29	15.5	9.1	1.69	10.9
					13.0 average
C Reliability		Mean ESD			
Post-nasal space	2	0.19	0.04	0.03	14.89
Shoulder	6	0.19	0.07	0.03	15.04
Sinuses	6	2.2	2	0.82	37.11
Whole spine/scoliosis	4	1.2	0.44	0.22	18.33

TABLE 5 *(continued)*

Examination	Number of hospitals	Mean ESD (mGy) or mean DAP (Gy cm^2)	Standard deviation on mean	Standard error on mean	Random uncertainty (% SEOM)
C Reliability *(continued)*		Mean DAP			
Abdominal angiography	2	85	23.4	16.55	19.47
Angiocardiography	3	26.8	5.5	3.18	11.85
Angioplasty	17	26	30	7.28	27.98
Aortography	3	34.5	17.1	9.87	28.62
Arteriography	12	27.2	14	4.04	14.86
Bile duct drainage	2	37.7	20.3	14.35	38.07
Bile duct stenting	4	54	17.4	8.70	16.11
Carotid/cerebral angiography	2	28	8	5.66	20.20
Cervical spine	5	0.49	0.22	0.10	20.08
Cystography	13	10.2	10.8	3.00	29.37
ERCP	11	15.1	10.2	3.08	20.37
Hysterosalpingography	10	4.2	1.3	0.41	9.79
Intravenous cholangiography	4	34	7.5	3.75	11.03
MCU	13	6.4	7.6	2.11	32.94
Myelography	6	12.3	6.4	2.61	21.24
Nephrostogram	10	9	9.9	3.13	34.79
Percutaneous cholangiography	2	31	11.9	8.41	27.14
Peritoneogram	1	12	1.4	1.40	11.67
Retrograde pyelogram	9	13	16.3	5.43	41.79
Sialography	5	6	9	4.02	67.08
Sinography	11	16.1	33	9.95	61.80
Small bowel enema	15	30	26	6.71	22.38
T-tube cholangiography	11	10	16.5	4.97	49.75
Urethrography	6	6	4.4	1.80	29.94
Venacavogram	3	21	16.8	9.70	46.19
Venography	9	3.7	2.8	0.93	25.23
					27.50 average

TABLE 6 Uncertainty and collective dose for each reliability rating

Reliability rating	Uncertainty in effective dose (relative)	Collective dose (man Sv)	Percentage collective dose
A	± 10%	10,319	53.5
B	± 25%	4,013	20.8
C	± 50%	3,274	17.0
D	Factor of 2	724	3.7
E	Factor of 3	970	5.0
Total		19,300	100

4 DISCUSSION

4.1 Trends in doses to the UK population

Although the per caput dose in the UK for medical and dental x-ray examinations is estimated to be 330 µSv for the financial year 1997/98, this is not significantly different from the previous estimate of 350 µSv for 1991[8]. The estimate for 1991 was very approximate (quantification of the uncertainty was not even attempted) and comparison with the new estimate is made even more uncertain by the fact that it was expressed in terms of effective dose *equivalent*, whereas the current estimate is in terms of effective dose. Moreover, this latest estimate is still subject to an uncertainty of ±30 µSv despite having a wealth of recent data available on both the frequency of x-ray examinations in the UK and typical doses to patients.

The lack of a significant increase or decrease in the per caput dose from medical and dental x-rays is perhaps not surprising in view of the reported stability in the total number of medical x-ray examinations over the past 15 years[11]. Dental radiology was seen to have increased substantially (by 50%), but the very low effective doses for dental x-rays would preclude their greater numbers from having a significant impact on the overall collective dose. There have, however, been substantial changes in the contributions from certain other types of x-ray examination or from specific imaging modalities. For some, the number of examinations performed in a year has changed while the dose per examination has remained much the same, whereas for others the doses have come down while the numbers have been stable. For example, higher collective doses have resulted from the increased frequency of relatively high dose imaging modalities such as CT and prolonged fluoroscopy used in angiographic or interventional procedures. As a result, the collective effective dose from CT has grown from about 3300 man Sv in 1989[7] to 7660 man Sv in 1997/98, an increase of 130% in eight years. Interventional radiology now contributes 1240 man Sv, which has probably increased by more than a factor of ten over the past decade. Lower collective doses are associated with the reduced utilisation of some moderate dose procedures that have been partially replaced by endoscopy (barium meals) or ultrasound (biliary and urinary tract examinations). However, the major factor responsible for reducing collective and per caput doses is the general fall in the dose per examination seen in the National Patient Dose Database[9] for the common radiographic and fluoroscopic examinations. The overall frequency of these conventional x-ray examinations has changed very little over the past ten years but the average drop of about 30% in the dose per examination means that their contribution to collective dose (including angiography) now stands at 10,400 man Sv, a decrease by about one-third from the estimate of 16,000 man Sv made in 1991.

Trends in the annual numbers of some common x-ray examinations and their contributions to collective dose over the 15 years between the 1983 and 1998 NRPB frequency surveys are shown in Figures 3 and 4.

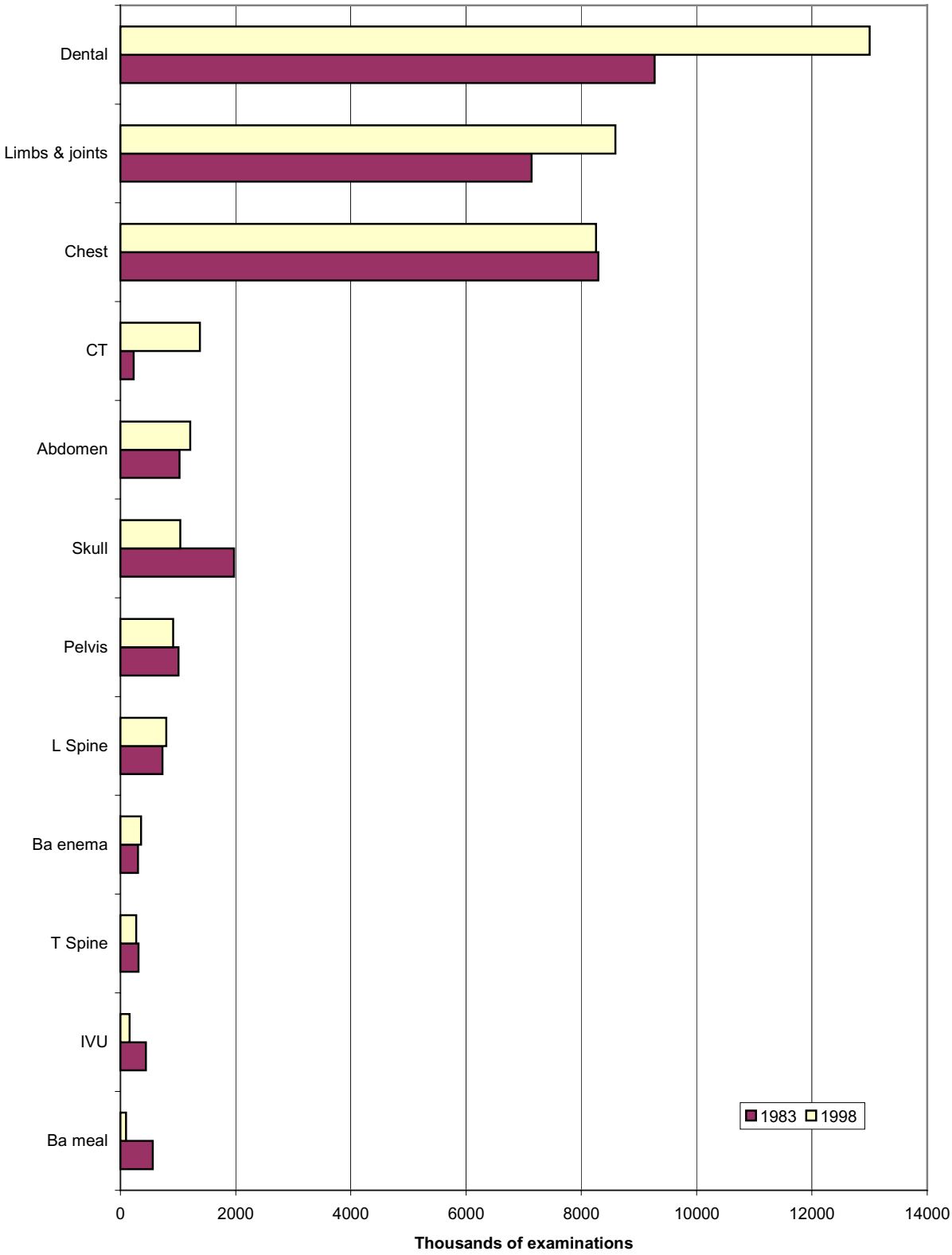

FIGURE 3 Trends in annual frequency of examinations in the UK 1983–1998

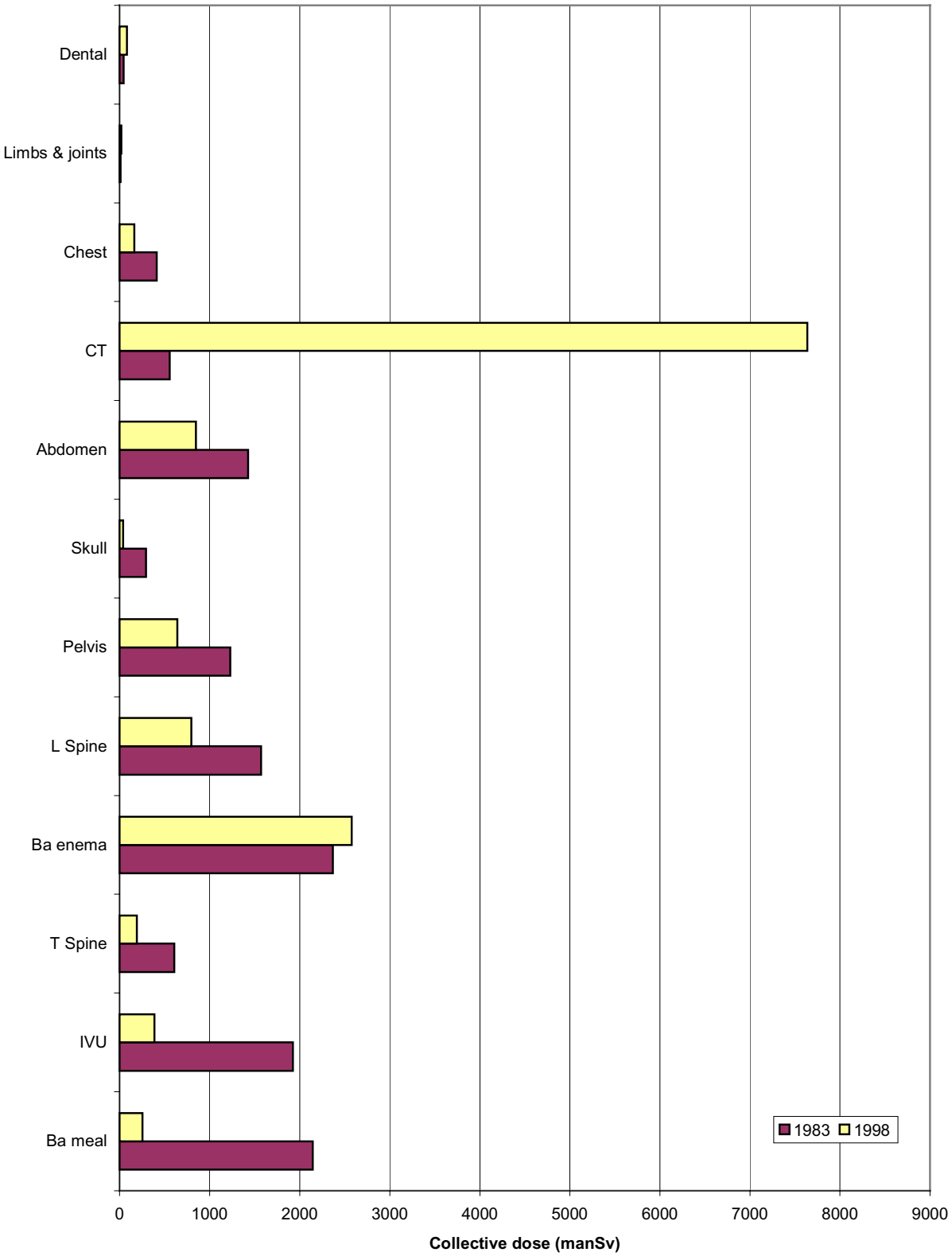

FIGURE 4 Trends in UK annual collective dose 1983–1998

Figure 3 shows the trends in frequency in the UK between 1983[21] and 1998[11] for a set of 12 types of examination for which data are available for both those years. (The data for 1983 were for Great Britain, but these have been scaled up by the ratio of the populations of the UK and GB.) There has been a noticeable increase in the estimated frequencies of dental and CT examinations, and a significant drop in the frequencies of skull, barium meal and IVU examinations.

Figure 4 shows the trends in annual UK collective dose between 1983 and 1998 for the same set of examinations as listed in Figure 3. The collective doses for 1983 were mostly calculated using effective doses taken from a survey of patient doses carried out in England in the mid-1980s[22]. For those conventional examinations which were not included in that survey (dental, limbs and joints), effective doses from the present report were used. The contribution from examinations of limbs and joints is so small as to be invisible in Figure 4. In the early 1980s CT head examinations were eight times more frequent than CT body examinations[21], and effective doses of 1.8 mSv for each CT head examination and 7 mSv for each CT body examination[7] were used to calculate the collective dose from CT in 1983. Head scans have fallen to 45% of all CT examinations by 1998 but the total number of CT examinations has increased by a factor of 5.8. CT consequently dominates the picture for 1998 in Figure 4, the collective dose having increased by over a factor of 12 since 1983. The collective doses from most of the other examinations in Figure 4, apart from barium enemas, have fallen substantially in the 15 year period.

4.2 Comparisons with other countries

A comparison of the estimated UK annual per caput dose of 330 μSv from medical radiology is made with similar data for other countries from the 1990s in Table 7, using information reported by UNSCEAR[24]. The data are arranged in order of decreasing size of the annual per caput effective dose. It can be seen that the UK has a low per caput dose compared with other nations with similarly developed systems of healthcare. It is notably about one-sixth of the value estimated for Germany and about one-third of the values given for France and Canada, although it should be recognised that there are likely to be large uncertainties associated with all of these values.

The relatively low value for the UK would appear to be due to both a lower frequency of x-ray examinations and generally lower doses per examination. This is evident from the Medical Radiation Exposures Annex of the UNSCEAR 2000 Report[24] where such statistics for the UK are compared with other countries in 'Healthcare Level I' (ie those having more than one physician per thousand population). Table 8 shows some data selected from Annex D of the UNSCEAR Report. The second and third columns show the annual numbers of medical x-ray procedures per thousand population for the UK and the average for Healthcare Level I. For 14 out of the 16 types of procedure shown (88%), UK frequencies are below the average frequencies for Healthcare Level I. The fourth and fifth columns show typical effective doses to patients for some common types of

TABLE 7 International comparison of annual per caput effective dose from medical radiology*

Country	Time period	Annual per caput effective dose (mSv)	Source
Germany	1990–92	1.9	23
France		1.0	24
Canada		0.94	24
Russia		0.9	24
Australia		0.8	25
Norway	1993	0.8	26
Poland		0.8	24
Bulgaria		0.75	24
Portugal	1991	0.71	27
Sweden		0.68	24
Romania		0.61	24
Netherlands		0.6	24
USA		0.5	24
Ukraine	1994	0.5	28
Finland		0.45	24
Spain (regional)	1990	0.4	29
Denmark		0.36	24
UK	**1997/98**	**0.33**	**This report**
Taiwan	1993	0.23	30
Brazil		0.09	24
China	1989	0.08	31
Malaysia	1994	0.05	32

*Based on Table 29 in Annex D, Volume 1, of the UNSCEAR 2000 Report[24].

diagnostic examinations for the UK and the average values for Healthcare Level I. For 10 out of the 12 types of examination for which doses are shown (83%), the UK doses are below the average doses for Healthcare Level I.

5 CONCLUSIONS

The annual per caput dose from medical and dental x-ray procedures in the UK has been estimated by combining the results of a recent survey of the frequency of 150 types of examinations with data for the 1990s on radiation doses from such examinations. The per caput dose from all x-ray imaging performed in NHS and private sector hospitals and clinics is estimated to be 330 μSv for the financial year 1997/98. This overall estimate is not significantly different from the previous rough estimate of 350 μSv for 1991, and is low in comparison with that for other countries with similarly developed systems of healthcare. This is due to both a lower frequency of x-ray examinations and to generally lower doses per examination in the UK.

TABLE 8 International comparison of examination frequencies and typical effective doses*

	Number of examinations per 1000 population per year		Typical effective dose (mSv)	
Type of examination	UK	Healthcare Level I	UK	Healthcare Level I
Chest	141	281	0.02	0.14
Limbs and joints	147	166		
Lumbar spine	19	48	1.3	1.8
Thoracic spine	5	13	0.7	1.4
Cervical spine	14	32		
Pelvis/hips	31	35	0.7	0.83
Head	28	59	0.04	0.07
Abdomen	21	41	0.7	0.53
Upper GI tract	4.9	42	2.6	3.6
Lower GI tract	6.1	8.7	7.2	6.4
Cholecystography	1.2	3.1		
Urography	4.6	12	2.4	3.7
Mammography	27	25	0.06	0.07
CT	21	57		
CT head			2	2.3
CT body			9	13.3
Angiography	5.2	7.6		
Interventional procedures	4.5	3.0		

*Selected from Tables 12, 15 and 30 in Annex D, Volume 1, of the UNSCEAR 2000 Report[24].

The relative contributions of some types of examination to the per caput dose or to the total collective dose to the UK population from medical x-rays have changed considerably since 1991. CT has more than doubled its contribution and is now responsible for 40% of the total. Angiographic and interventional procedures, which often involve prolonged fluoroscopy and hence result in high individual doses, have also increased in frequency and currently provide about 10% and 6% of the total, respectively. The more conventional fluoroscopic and radiographic examinations are now making a smaller contribution. This is partly due to a drop in frequency of examinations such as barium meals that are being slowly replaced by endoscopy, and of biliary and urinary tract examinations where ultrasound imaging provides a viable alternative. However, the major factor responsible for reducing the per caput and collective doses for these conventional x-ray examinations is the average drop of about 30% in the dose per examination, seen in the 1995 review of the National Patient Dose Database[9]. Their contribution to collective dose now stands at about 8500 man Sv (if the 'unassignable examinations' are included) or 44% of the total, and represents a reduction by nearly a factor of two since 1991. The relative contributions of conventional, CT, angiographic and interventional procedures to the per caput dose from all medical x-ray examinations are shown on the pie-chart in Figure 5.

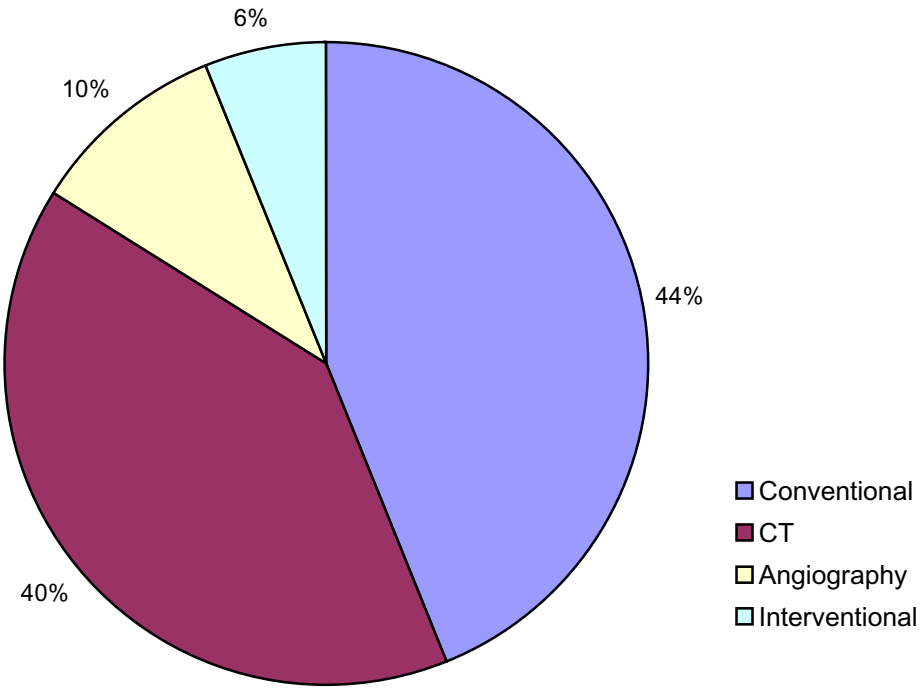

FIGURE 5 Major contributors to UK collective dose from medical x-rays

The increasing attention given in recent years to radiation protection for conventional examinations, with the development of national patient dosimetry protocols and reference doses, has played a significant part in this substantial reduction in collective dose. Widespread local monitoring of patient doses and x-ray imaging performance and comparison with national norms have undoubtedly encouraged the adoption of dose-efficient procedures and the introduction of dose-saving features into x-ray imaging equipment. With the now much increased contributions of CT, angiography and interventional radiology to the per caput dose, there is a clear need to develop radiation protection and optimisation activities for these high dose procedures to the same level as has been already achieved for conventional radiology.

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APPENDIX:

DATA USED TO CALCULATE COLLECTIVE DOSE IN THE UK

Data used to calculate collective dose in the UK

Category Examination	No. of exams in the UK	ESD mGy	ESD Conversion factor mSv/mGy	DAP Gy cm^2	DAP Conversion factor mSv/(Gy cm^2)	Effective dose, *E* mSv	Source of data	No. of patients	No. of hospitals	Reliability rating for *E*	Collective dose man Sv	Collective dose % of total
Conventional radiography												
Skull and facial bones												
Nasal bones	32,706					0.01	Facial bones and cephalometry			E	0.33	0.002
Facial bones	191,489	1	0.01			0.01	NPDD	3	1	D	1.91	0.010
Mastoids	3,358					0.06	Skull			E	0.20	0.001
Skull/p fossa/ optic foramina/iams	551,066	2.5, 1.4, 1.9	0.01			0.06	NPDD (PA+LAT+0.75AP) 1	2580	136	A	33.06	0.171
				1.46	0.028	0.041	NPDD (complete exam)	14	3			
Cephalometry	78,383					0.01	2, 3	40,000		D	0.78	0.004
Mandible	45,707	1.35	0.01			0.014	NPDD	2	1	D	0.62	0.003
Temporo-mandibular joints	14,297					0.012	Mean of mandible and cephalometry			E	0.17	0.001
Sinuses and antra	129,824	2.2	0.01			0.022	NPDD	50	6	C	2.86	0.015
Head – soft tissue												
Dacrocystography	3,892			1.8	0.028	0.05	NPDD	1	1	D	0.20	0.001
Pharyngography	984					0.06	As skull			E	0.06	0.000
Post-nasal space	11,728	0.2	0.01			0.002	NPDD	20	2	C	0.02	0.000
Salivary glands	5,027					0.056	As sialography			E	0.28	0.001
Sialography	12,631			2	0.028	0.056	NPDD	24	5	C	0.71	0.004
Eyes	36,522	2.5	0.01			0.025	NPDD skull AP			E	0.91	0.005
Teeth intraoral (hospital)												
Teeth, up to 2 films	172,213					0.005	3			D	0.86	0.004
Teeth >2 films	4,873					0.015	3			D	0.07	0.000
Teeth, panoramic (hospital)	392,853					0.01	3			C	3.93	0.020
Dental practice												
Intraoral	9,562,500					0.005	4			D	47.81	0.248
Panoramic	2,937,500					0.01	3			D	29.38	0.152

Category Examination	No. of exams in the UK	ESD mGy	ESD Conversion factor mSv/mGy	DAP Gy cm^2	DAP Conversion factor mSv/(Gy cm^2)	Effective dose, *E* mSv	Source of data	No. of patients	No. of hospitals	Reliability rating for *E*	Collective dose man Sv	Collective dose % of total
Cerebral angiography												
Carotid/cerebral angiography	11,999			48.5	0.087	4	5	90	1	C	48.00	0.249
				28	0.028	0.78	NPDD	55	2			
				42			6	57	2			
Neck - soft tissue												
Soft tissues of neck	39,775			0.1	0.03	0.003	NPDD	1	1	D	0.12	0.001
Larynx	342					0.07	As Cspine			E	0.02	0.000
Laryngography	202					0.07	As Cspine			E	0.01	0.000
Myelography												
Myelography	2,104			12.3	0.2	2.46	NPDD	68	6	C	5.18	0.027
Discography	2,239					1.3	7	75	2	C	2.91	0.015
Lumbar radiculography	483					3.5	7	106	2	C	1.69	0.009
Cervical spine	858,547	1.7, 0.3	0.04, 0.006			0.07	NPDD (AP+LAT)	83	19	C	60.1	0.311
				0.49	0.13	0.064	NPDD (complete exam)	104	5			
Thoracic spine	281,215					0.7	8 (AP+LAT)			B	196.8	1.020
		3.9, 10.8	0.092, 0.026			0.64	NPDD (AP+LAT)	1277	81			
				4.2	0.19	0.80	NPDD (complete exam)	38	8			
Lumbar spine	824,763					1.0	8 (AP+LAT)			A	824.8	4.274
		6,14.5	0.107, 0.025			1.0	NPDD (AP+LAT)	9892	363			
				5.7	0.21	1.2	NPDD (complete exam)	592	33			
Lumbo-sacral joint												
LSJ	267,505					0.3	8			A	80.25	0.416
		28.1	0.012			0.34	NPDD	2210	222			
Sacro-iliac joints	42,248					0.17	As sacrum and coccyx			E	7.06	0.037
		5.4	0.012			0.06	NPDD	1	1			
Sacrum and coccyx	29,148	13.9	0.012			0.17	NPDD	6	4	D	4.86	0.025

Category Examination	No. of exams in the UK	ESD mGy	Conversion factor mSv/mGy	DAP Gy cm^2	Conversion factor mSv/(Gy cm^2)	Effective dose, *E* mSv	Source of data	No. of patients	No. of hospitals	Reliability rating for *E*	Collective dose man Sv	 % of total
Whole spine / scoliosis	33,614					0.1				C	3.36	0.017
		0.53, 0.63	0.1,0.025			0.07	NPDD (AP/PA+LAT)	78	4			
						0.12	9 Sweden	7				
						0.14	10 USA	61	1			
		0.08					11	283				
Shoulder girdle												
Shoulder	652,160			0.3	0.036	0.011	NPDD	21	2	C	7.04	0.036
		0.19	0.007			0.001	NPDD AP	3	3			
		0.31, 0.98	0.007			0.009	12 (AP+LAT) Australia	4	1			
Acromioclavicular joints	13,855					0.01	As shoulder			E	0.14	0.001
Clavicle/collar bone	63,252					0.01	As shoulder			E	0.63	0.003
Scapula	12,972					0.01	As shoulder			E	0.13	0.001
Sternoclavicular joint	4,413					0.01	As shoulder			E	0.04	0.000
Sternum	28,901					0.01	As shoulder			E	0.29	0.001
Upper arm	138,912	0.15	0.005			0.0008	12	4	1	D	0.10	0.001
Elbow	435,202			0.1	0.01	0.001	NPDD	53	6	D	0.44	0.002
Forearm, wrist and hand												
Fingers	470,137					0.0005	As hand			E	0.24	0.001
Hand	817,873	0.1	0.005			0.0005	NPDD	6	6	D	0.41	0.002
				0.04	0.01	0.0004	NPDD	1	1			
Radius and ulna/forearm	269,516					0.001	Adjusted to match elbow			D	0.27	0.001
		0.6	0.005			0.003	NPDD	1	1			
Thumb	225,226					0.0005	As hand			E	0.11	0.001
Wrist/scaphoid	1,177,460	0.1	0.005			0.0005	NPDD	197	8	D	0.59	0.003
Pelvis	919,740					0.7	8			A	643.8	3.336
		4.2	0.16			0.67	NPDD (AP)	4281	285			
				2.6	0.29	0.75	NPDD	285	26			

Category Examination	No. of exams in the UK	ESD mGy	ESD Conversion factor mSv/mGy	DAP Gy cm^2	DAP Conversion factor mSv/(Gy cm^2)	Effective dose, *E* mSv	Source of data	No. of patients	No. of hospitals	Reliability rating for *E*	Collective dose man Sv	Collective dose % of total
Hip	853,371					0.35				B	298.7	1.548
		2.7,3.7	0.06,0.006			0.18	NPDD (AP+LAT)	189	20			
				3.1	0.175	0.54	NPDD	10	5			
		3.8, 0.63	0.06			0.27	12	14	1			
Orthopaedic pinning (inc hip)	32,118			2.6		0.7	13	55	1	C	22.48	0.117
Femur	191,294	0.5	0.005			0.0025	12	18	1	D	0.48	0.002
		0.13, 0.14	0.005			0.0014	NPDD (AP+LAT)	5	1			
Leg length	16,844					0.184	14	13	1	D	3.10	0.016
Knee, lower leg, ankle and foot												
Ankle	1,003,438	0.42	0.005			0.002	NPDD (AP+LAT)	103	6	D	2.01	0.010
				0.1	0.01	0.001	NPDD	12	2			
Foot	1,001,151			0.06	0.01	0.0006	NPDD	116	6	D	0.60	0.003
		0.1	0.005			0.0005	NPDD	1	1			
Knee	1,511,689	0.49	0.005			0.0025	NPDD (AP+LAT)	404	28	D	3.70	0.019
				0.15	0.01	0.0015	NPDD	52	2			
Calcaneum/heel	75,409			0.09	0.01	0.0009	NPDD	5	1	D	0.07	0.000
Patella	18,431					0.0025	As knee			E	0.05	0.000
Tibia and fibula	366,733					0.002	Adjusted to match ankle			D	0.73	0.004
		0.1	0.005			0.0005	NPDD	33	8			
Toes	146,610					0.0006	As foot			E	0.09	0.000
Arthrography	8,752			1.7	0.1	0.17	NPDD all	82	9	D	1.49	0.008
Skeletal survey	12,032			18	0.1	1.80	NPDD	2	1	D	21.66	0.112
Chest												
Chest/ribs	8,273,369					0.02	8 (PA only)			A	165.5	0.857
		0.16	0.1			0.016	NPDD (PA)	10361	373			
Thoracic inlet	12,680					0.02	As chest			E	0.25	0.001
Bronchography	471			1.74	0.12	0.21	NPDD	1	1	D	0.10	0.001

Category Examination	No. of exams in the UK	ESD mGy	Conversion factor mSv/mGy	DAP Gy cm^2	Conversion factor mSv/(Gy cm^2)	Effective dose, *E* mSv	Source of data	No. of patients	No. of hospitals	Reliability rating for *E*	Collective dose man Sv	 % of total
Mammography		Mean glandular dose for mammography mgd			Conversion factor mSv/mgd							
Mammography symptomatic	326,303	2 views of each breast				0.37	15		1	C	120.7	0.626
						0.33	16, 17		1			
Mammography screening 1st round	374,000	3.7 mgd for 2 views			0.1	0.37	15	3035	171	A	138.4	0.717
		3.3 mgd for 2 views			0.1	0.33	17	4633	92			
Mammography screening subsequent rounds	960,000	2.0 mgd for 1 view each breast			0.1	0.2	15	5694	171	A	192.0	0.995
		1.8 mgd for 1 view each breast			0.1	0.18	17, 18					
Mammography recall for assessment	66,000	2.5 films per procedure				0.23	19	50000	6	C	15.18	0.079
Pulmonary angiography												
Pulmonary arteriography	3,030			47	0.12	5.6	NPDD pulm + bronch angiog	5	2	D	17.09	0.089
Arterial pressures	1,457					7	As arteriography			E	10.20	0.053
Sup venacavography	900					2.5	As venacavogram			C	2.27	0.012
Venacavogram	142			21	0.12	2.5	NPDD	22	3	C	0.36	0.002
Abdominal angiography												
Inf venacavography	714					2.5	As venacavogram			C	1.80	0.009
Mesenteric angiography	2,057			85	0.26	22.1	NPDD abdominal angiog	338	2	C	45.45	0.236
				112			6	108	1			
Renal and visceral arteriography	9,940			92	0.26	23.9	6	56	2	C	237.8	1.232
				91		12.7	20 Spain	29				
Aortography												
Thoracic aortography/ arch angiogram	1,732			34.5	0.12	4.1	NPDD aortog + arch aort	287	3	C	7.17	0.037
Abdominal aortography	806			98	0.26	25.5	21	41	1	C	20.54	0.106
						14	22 USA	19				

Category Examination	No. of exams in the UK	ESD mGy	ESD Conversion factor mSv/mGy	DAP Gy cm^2	DAP Conversion factor mSv/(Gy cm^2)	Effective dose, *E* mSv	Source of data	No. of patients	No. of hospitals	Reliability rating for *E*	Collective dose man Sv	Collective dose % of total
Aortography	8,623					11	Weighted mean of thoracic and abdominal			C	94.85	0.492
Angiocardiography												
Angiocardiography and coronary angiography	159,137			55	0.12	6.6	NPDD	4	1	C	1050	5.443
				26	0.12	3.1	NPDD	187	2			
				14		3.1	23	100	1			
						6	24	~3500	4			
				46.4		9.1	25	2300	2			
				44			26	>8	1			
				63			27 Sweden	65	1			
						3.4	28 Australia	210				
						10.6	29 Finland	Not stated	14			
				30	0.183	5.6	30 Greece	29	1			
Cardiac catheter (no angio-cardiogram)	3,733					7	As arteriography			E	26.13	0.135
Peripheral angiography												
Arteriography, all types	47,486			27.2	0.26	7.1	NPDD angiogram + arteriogram	759	12	C	335.8	1.740
				64			6	571	4			
				26.3		4.0	31 Australia	25	1			
Phlebography/ venography of a limb	69,417			3.7	0.1	0.37	NPDD arm or leg	158	9	C	25.68	0.133
				23			21	26	1			
Abdomen (plain film)	1,217,192					0.7	8			A	852.0	4.415
		5.4	0.14			0.76	NPDD	5500	302			
				3.1	0.26	0.81	NPDD	224	20			
Oesophagus												
Ba swallow	123,751					1.5	8	4258	54	B	185.6	0.962
Stomach and duodenum												
Ba meal	98,581					2.6	NPDD	9718	89	B	256.3	1.328

Category Examination	No. of exams in the UK	ESD		DAP		Effective dose, *E* mSv	Source of data	No. of patients	No. of hospitals	Reliability rating for *E*	Collective dose	
		mGy	Conversion factor mSv/mGy	Gy cm^2	Conversion factor mSv/(Gy cm^2)						man Sv	% of total
Small intestine												
Ba follow-through/ small bowel meal	34,653					3	8	886	29	B	104	0.539
Small bowel enema	6,436			30	0.26	7.8	NPDD	176	15	C	50.20	0.260
Colon												
Ba enema	359,436					7.2	NPDD	22586	87	B	2588	13.41
Other abdominal investigations												
Endoscopy	958					0.3	cf small bowel biopsy			E	0.29	0.001
Fistulogram	1,583			6.4	0.26	1.7	NPDD	18	5	D	2.63	0.014
Herniography	2,719			14	0.26	3.6	NPDD	8	2	D	9.90	0.051
Loopogram	1,351			5	0.26	1.3	NPDD	4	4	D	1.76	0.009
Peritoneogram	177			12	0.26	3.1	NPDD	26	1	C	0.55	0.003
Ileoanal pouchogram	225			15	0.26	3.9	NPDD	7	3	D	0.88	0.005
Sinography	4,739			16	0.26	4.2	NPDD	71	11	C	19.71	0.102
Biliary system												
Preliminary cholecystogram	441					2	Lowest cholang			E	0.88	0.005
Cholangiography, operative	7,813					3	cf T-tube chol			E	23.44	0.121
Cholangiography, infusion	71					9	cf intravenous chol			E	0.64	0.003
Cholangiography, intravenous	415			34	0.26	8.8	NPDD	25	4	C	3.67	0.019
Oral cholecystography	2,341			12	0.26	3.1	NPDD	10	3	D	7.30	0.038
ERCP	48,677			15	0.26	3.9	NPDD	525	11	C	190	0.984
PTC	4,412			31	0.26	8.1	NPDD	48	2	C	35.56	0.184
T-tube cholangiography, post-op	3,457			10	0.26	2.6	NPDD	149	11	C	8.99	0.047

Category Examination	No. of exams in the UK	ESD mGy	ESD Conversion factor mSv/mGy	DAP Gy cm^2	DAP Conversion factor mSv/(Gy cm^2)	Effective dose, *E* mSv	Source of data	No. of patients	No. of hospitals	Reliability rating for *E*	Collective dose man Sv	Collective dose % of total
Kidneys and ureters												
Kidney, exposed	81					2.5	Mean of nephrostomy and nephrostogram			E	0.20	0.001
Antegrade pyelography (percutaneous)	688			3.5	0.18	0.6	NPDD	8	5	D	0.43	0.002
Nephrostogram, post-op	6,024			9	0.18	1.6	NPDD	57	10	C	9.76	0.051
Retrograde pyelogram	7,938			13	0.18	2.3	NPDD	27	9	C	18.58	0.096
IVU	162,502					2.4	NPDD	1141	29	B	390.0	2.021
Bladder and urethra												
Cystourethrography	1,797					1.5	Mean of cystography and urethrography			C	2.70	0.014
Cystometrography	26,511			7	0.18	1.3	NPDD	70	3	C	33.40	0.173
Cystography	5,645			10	0.18	1.8	NPDD	197	13	C	10.16	0.053
Excretion urography/MCU	45,849			6.4	0.18	1.2	NPDD	995	13	C	52.82	0.274
Urethrography	3,138			6	0.18	1.1	NPDD	19	6	C	3.39	0.018
Gynaecology												
Pelvimetry	5,915	5.1	0.156			0.8	NPDD (AP or LAT)	28	2	C	4.71	0.024
				1.4	0.29	0.41	NPDD	1	1			
Hysterosalpingogram	21,713			4	0.29	1.2	NPDD	201	10	C	25.19	0.131
Lymphangiogram	128			0.3	0.2	0.06	NPDD	1	1	D	0.01	0.000
Tomography other than of teeth	2,722	3	0.05			0.15	32 USA			D	0.41	0.002
Bone mineral densitometry	27,265					0.002	33 USA			C	0.05	0.000
						0.0005 to 0.035	34 Italy					
						0.0002 to 0.01	35 USA					

Category Examination	No. of exams in the UK	ESD		DAP		Effective dose, *E* mSv	Source of data	No. of patients	No. of hospitals	Reliability rating for *E*	Collective dose	
		mGy	Conversion factor mSv/mGy	Gy cm^2	Conversion factor mSv/(Gy cm^2)						man Sv	% of total
Computed tomography												
CT head	618,391					2	36			A	1237	6.409
CT neck	24,332					2.5	36 cervical spine			A	60.83	0.315
CT abdomen	297,244					10	8			A	2972	15.40
CT chest	192,885					8	36			A	1543	7.996
CT pelvis	139,722					10	8			A	1397	7.240
CT extremity	18,401					0.5	37 Norway			E	9.20	0.048
CT spine	63,183					4	36 mean of lumbar + thoracic			A	252.7	1.310
CT pelvimetry	8,200					0.2	36 (Table 18) SPR pelvis AP + LAT			A	1.64	0.008
CT interventional	13,184					10	Highest CT			E	131.8	0.683
CT bone mineral densitometry	1,594					1	38 USA			D	1.59	0.008
						0.3 to 1	33 USA					
						0.1	35 USA					
CT angiography	5,129					6	39 Germany			D	30.77	0.159
CT other	4,771					5	Mean of all CT			E	23.85	0.124
Interventional radiology												
Biopsy												
Pathological specimen	4,763					1.6	As biopsy			E	7.43	0.039
Biopsy	23,089			6	0.26	1.6	NPDD	32	8	D	36.02	0.187
Small bowel biopsy	149			1	0.26	0.26	NPDD	15	1	D	0.04	0.000
Venous sampling	202					0.4	cf venography			E	0.08	0.000

Category Examination	No. of exams in the UK	ESD mGy	ESD Conversion factor mSv/mGy	DAP Gy cm^2	DAP Conversion factor mSv/(Gy cm^2)	Effective dose, *E* mSv	Source of data	No. of patients	No. of hospitals	Reliability rating for *E*	Collective dose man Sv	Collective dose % of total
Biliary and urinary systems												
Bile duct drainage	3,250			38	0.26	9.9	NPDD	8	2	C	32.11	0.166
				43			21	86	1			
				69			40 Spain	10	<10			
				150		38	41 Canary Islands	18	1			
Bile duct, dilatation and stenting	6,224			54	0.26	14.0	NPDD	15	4	C	87.39	0.453
				51			21	74	1			
				43		7	42 Saudi Arabia	30	1			
Bile duct, stone extraction	1,929			27	0.26	7.0	NPDD	29	2	D	13.54	0.070
Lithotripsy	23,672			5	0.26	1.3	NPDD	40	1	D	30.77	0.159
Nephrostomy	7,326			13	0.26	3.4	NPDD	68	5	D	24.76	0.128
				43		7	42 Saudi Arabia	35	1			
				56		14	41 Canary Islands	54	1			
Ureteric stenting	3,027			18	0.26	4.7	NPDD	15	3	D	14.16	0.073
Kidney stent insertion	2,540			49	0.26	12.7	NPDD	5	3	D	32.36	0.168
Cardiovascular												
Angioplasty	36,680			26	0.26	6.8	NPDD	430	17	C	248	1.285
				67			21	100	1			
				48		5.3	42 Saudi Arabia	16	1			
PTCA	22,440			58	0.26	15.1	NPDD	49	1	C	338.4	1.754
				71.2		14	25	225	2			
				145			43 USA	223	1			
				46			44 Australia	17	1			
				87.5			40 Spain	45	<10			
				93			45 France	90	3			
				50	0.183	9.1	30 Greece	39	1			
Embolisation	3,695			75	0.26	19.5	NPDD	12	5	D	72.05	0.373
				105			21	27	1			

		ESD		DAP							Collective dose	
Category Examination	No. of exams in the UK	mGy	Conversion factor mSv/mGy	Gy cm^2	Conversion factor mSv/(Gy cm^2)	Effective dose, *E* mSv	Source of data	No. of patients	No. of hospitals	Reliability rating for *E*	man Sv	% of total
Management of varicocele	418			51		6.4	46	41	1	C	2.67	0.014
				106		25.7	47 Spain	10				
				131	0.29	38.0	NPDD	1	1			
				75		17	41 Canary Islands	20	1			
Neuro-embolisation	1,395			202	0.028	5.7	NPDD	1	1	D	7.89	0.041
				122.2	0.087	10.6	5	8	1			
				116		1.7	48 USA	8				
				105		10.5	42 Saudi Arabia	5	1			
Hickman line	9,762			4.8	0.1	0.48	NPDD	151	3	D	4.69	0.024
				10.9			21	71	1			
Insertion of pacemaker	28,688			7	0.1	0.7	NPDD	140	7	D	20.08	0.104
RF cardiac catheter ablation	3,976			91.1		17.3	25	81	1	D	68.78	0.356
				30	0.1	3	NPDD	14	1			
				44			44 Australia	17	1			
						21	49 USA	859	9			
Thrombolysis	3,566			13.5	0.26	3.5	NPDD	5	3	D	12.52	0.065
TIPS	97			206	0.26	53.6	NPDD	10	2	D	5.18	0.027
				182			21	56	1			
				161		18.7	50 Netherlands	23				
				524		84	42 Saudi Arabia	4	1			
Valvuloplasty	314			162		29.3	25	40	1	C	9.21	0.048
Vascular stenting	9,554			40	0.26	10.4	NPDD	14	6	D	99.36	0.515
				42		5.8	51	44	1			
Insertion of caval filters	1,197			48	0.26	12.5	NPDD	4	4	D	14.94	0.077
Removal of introvascular foreign body	30					7	As arteriography			E	0.21	0.001

		ESD		DAP							Collective dose	
Category Examination	No. of exams in the UK	mGy	Conversion factor mSv/mGy	Gy cm^2	Conversion factor mSv/(Gy cm^2)	Effective dose, *E* mSv	Source of data	No. of patients	No. of hospitals	Reliability rating for *E*	man Sv	% of total
Gastrointestinal												
Feeding tube	823			13	0.26	3.4	NPDD	16	5	D	2.78	0.014
Gastrostomy	1,630			13	0.26	3.4	NPDD	15	4	D	5.51	0.029
Dilation/stenting of oesophagus	7,733			15	0.1	1.5	NPDD	96	4	D	11.60	0.060
Dilation of pyloric stenosis	31			27	0.26	7.0	NPDD	4	1	D	0.22	0.001
Colonic stent	146					7	As barium enema			E	1.02	0.005
Nerve injection under imaging control	35,758			1.7		0.2	13	22	1	C	7.15	0.037
				9	0.2	1.8	NPDD	1	1			
Other interventional	3,173					9	Mean of all interventional doses used			E	28.56	0.148
Unassignable examinations	298,113					2.1	2/3 fluoro at 3 mSv, 1/3 FB demo at 0.4 mSv				626.0	3.24
Total	**41,541,000**										**19,298**	**100**

Source of data

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