Frequency and Collective Dose for Medical and Dental X-ray Examinations in the UK, 2008

D Hart, B F Wall, M C Hillier and P C Shrimpton

ABSTRACT

This report presents the results of a study of frequency and collective dose for medical and dental X-ray examinations in the UK in 2008. The frequency data were collected from the radiology information systems (RIS) at a sample of 29 NHS Trusts in England. The total number of medical and dental X-ray examinations carried out in the UK, both inside and outside the NHS, is estimated by extrapolation to be 46 million in 2008, a 10% rise on the number for the financial year 1997/98. Combining effective doses (2007 definition) for specific X-ray examinations with the frequency of those examinations gives an estimate of collective dose for the UK in 2008 of 24,700 man Sv (± 12%). A very similar figure of 24,250 man Sv is obtained if the 1991 definition of effective dose is used. The UK per caput dose is therefore around 0.4 mSv per year, which has increased by 23% over that for 1997/98. This increase is mainly due to the greater prevalence of computed tomography (CT) examinations, which now account for 68% of the collective dose from all medical and dental X-ray examinations. Conventional radiographic and fluoroscopic examinations contribute only 19% of the collective dose, despite constituting 90% of all X-ray examinations. Angiography and interventional procedures contribute about 5% and 8%, respectively, to the UK collective dose from all X-ray examinations. Despite the increase in the annual UK per caput dose from 0.33 to 0.4 mSv, it is still low in comparison with other countries having similar levels of healthcare. This is due to both a lower frequency of X-ray examinations per head of population and generally lower doses per examination in the UK.

Centre for Radiation, Chemical and Environmental Hazards
Chilton, Didcot,
Oxfordshire OX11 0RQ

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EXECUTIVE SUMMARY

The population of the UK is exposed to ionising radiation to a greater extent from medical and dental X-ray examinations than from any other artificial source. The latest estimate has put the contribution from patients undergoing X-ray examinations at 90% of the total exposure from all artificial sources. A detailed assessment of the population dose from X-rays was previously carried out by HPA (NRPB) for 1997, since when technological and clinical developments, particularly in relation to computed tomography (CT), have fuelled the increasing application of X-rays for diagnosis and treatment.

This report contains a detailed analysis of the numbers of medical and dental X-ray examinations performed in the UK in 2008. These examinations include computed tomography (CT), conventional radiography, fluoroscopy, and interventional procedures. CT involves rotating the X-ray tube around the patient and using a computer to derive cross-sectional images. In the past, conventional radiography was entirely carried out using X-ray films, but now it mainly uses digital images stored on a computer. Both methods for conventional radiography are included in this analysis. Fluoroscopy gives a real-time image of the patient. Interventional procedures are minimally invasive surgical procedures which use X-ray imaging (e.g. fluoroscopy) for guidance.

Radiology departments also carry out examinations using nuclear medicine, but since this does not involve X-rays it is excluded from this analysis. Radiology departments also use ultrasound and magnetic resonance imaging, but neither of these uses ionising radiation, so they are excluded from this analysis. Radiotherapy exposures are also deliberately excluded.

A frequency survey has been performed to evaluate the numbers of every type of radiological X-ray examination conducted in the UK during 2008, both within and outside the National Health Service. The survey used detailed information derived from radiology information systems at 29 English NHS Trusts. Extrapolation of the sample data to the whole of England was carried out using NHS radiology statistics from the English Department of Health. Additional data was obtained to cover X-ray imaging outside NHS hospitals, for example, dentists, chiropractors and independent hospitals. Extrapolation to the whole of the UK was carried out on the basis of population size. The total number of medical and dental X-ray examinations carried out in the UK in the calendar year 2008 is estimated to be 46 million. This is an increase of 10% on the estimate for 1997.

To estimate the collective dose from X-ray examinations in the UK it was necessary to find a typical effective dose for each type of examination. Most of these doses were derived from the National Patient Dose Database maintained by the HPA. The rest of the doses were taken from the published literature. The resulting collective dose, when divided by the total UK population, gives a per caput dose of 0.4 millisievert per year. This is 23% higher than our estimate for 1997. This increase is probably due to a doubling in the number of CT examinations over that ten year period. CT now accounts for 68% of the collective dose from all medical and dental X-ray examinations. Conventional radiographic and fluoroscopic examinations contribute only 19%, despite constituting 90% of all X-ray examinations. Angiography and interventional procedures

contribute 5% and 8% respectively. Despite the increase in the annual UK per caput dose, it is still low in comparison with other countries having similar levels of healthcare. This is due to both a lower frequency of X-ray examinations per head of population, and generally lower doses per examination in the UK.

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1 INTRODUCTION

Medical radiology is by far the largest artificial source of exposure to ionising radiation (UNSCEAR, 2010) and hence a key topic in radiation protection. The most recent estimate by the HPA puts the contribution from medical and dental X-ray examinations at 90% of the dose from all artificial sources of exposure in the UK, with diagnostic nuclear medicine procedures (involving the administration of unsealed radiopharmaceuticals) accounting for a further 7% of this total (Watson et al, 2005). Article 12 of the European Commission's Medical Exposure Directive of 1997 requires Member States to ensure that the distribution of individual dose estimates from medical exposure is determined for the population (European Commission, 1997). One benefit from constructing an estimate of the population dose is that it allows comparison of the contributions from different types of X-ray examination. Such information can provide guidance on where best to concentrate efforts on dose reduction. Another benefit is the capability to monitor any trend in annual per caput effective dose associated with changes in radiology practice.

The most recent detailed national survey of the frequency of medical and dental X-ray examinations in the UK was performed for the financial year 1997/98 by NRPB (Tanner et al, 2000). That analysis estimated an annual total of 41.5 million such examinations and formed the basis for a detailed calculation of the UK collective dose from medical and dental X-ray examinations that was published in 2002 (Hart and Wall, 2002). The annual per caput effective dose from all medical and dental X-ray examinations was estimated at 330 microsieverts. This was updated to 380 microsieverts in a further crude estimate for 2001/02 (Hart and Wall, 2004).

This report presents the results of a new study of frequency and collective dose from X-ray examinations for the year 2008. It follows the recommended methods published by the European Commission (Wall et al, 2008) for estimating population doses from medical X-ray procedures. Diagnostic nuclear medicine procedures are not included in the present assessment, but were the topic of a previous national study (Hart and Wall, 2005).

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 survey has been carried out to provide information on the annual numbers of X-ray examinations in the UK in 2008, as discussed in Section 2.1. Estimates of the mean effective dose for each examination were based on the latest tissue weighting factors given in ICRP Publication 103 (ICRP, 2007) and also the old weighting factors given in ICRP Publication 60 (ICRP, 1991), in order to make a direct comparison with our previous estimate of collective dose. Doses were obtained from a number of sources, the predominant one being the 2005 version of the National

Patient Dose Database maintained by HPA (Hart et al, 2007). This contained dose data collected in the period from 2001 to 2005 covering more than 300 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 X-ray examination frequency survey was based on data gathered from two English NHS Strategic Health Authorities (SHA) out of a total of 10 in England. An SHA is large enough to have all the medical specialties requiring the use of diagnostic radiology within it. Two SHAs were chosen so that the pattern of X-ray examinations in the two regions could be compared. The two SHAs were the South-West and the West Midlands. These were the SHAs with the closest match to the number of X-ray examinations per head of population for England as a whole (see Table 1). The data for Table 1 were derived from the annual statistics on the total numbers of X-ray examinations provided to the Department of Health by NHS trusts, that is the KH12 returns (Department of Health, 2009).

TABLE 1 SHA workload and examinations per caput (2008)

SHA	% of total X-ray exams	X-ray exams per head of population
East Midlands	6.65	0.377
East of England	9.13	0.415
South Central	6.99	0.432
West Midlands	10.57	0.489
South West	9.67	0.489
Yorkshire and Humber	10.38	0.500
South East	8.46	0.507
North West	14.65	0.549
London	17.50	0.557
North East	6.01	0.588
England	*100*	*0.492*

The radiology information system (RIS)/ picture archiving and communications system (PACS) manager at all trusts with acute hospitals in the two SHAs was asked for frequency data covering a one year period. Data were accepted for either the financial years 2007/08 or 2008/09, or for the calendar year 2008.There were 37 trusts with acute hospitals in the two SHAs. 29 out of these 37 trusts sent details on the numbers of medical X-ray examinations of different type that they had performed in the year, as recorded in their computerised radiology information systems. A systematic check for missing data was carried out to ensure that data from all cardiology departments was obtained even though they are often not covered by the radiology information system. A similar check was also carried out for symptomatic mammography, bone densitometry,

and dental X-ray examinations. If any of these specialities were not included in the RIS data, contact was made with the trust to obtain the numbers from other sources.

The data from each of these 29 trusts were compared with the 3 categories (CT, radiography and fluoroscopy) in the KH12 returns (Department of Health, 2009). This comparison was done for the appropriate financial years (2007/08 or 2008/09) to check whether the numbers in the KH12 returns were similar to ours. The comparison could only be performed in an approximate way for data supplied for the calendar year 2008, in which case the KH12s for 2008/09 were used.

Despite some variations in the terminology adopted by the trusts for describing the different types of X-ray examination, all of the data were allocated to 231 distinct and identifiable types of examination. The survey data were extrapolated to the whole of the English NHS using the KH12 returns (Department of Health, 2009). The data were then extrapolated to the whole of the UK on the basis of the relative populations of England and the UK for 2008.

Information was also gathered on the annual numbers of X-ray examinations conducted in general dental practice, independent hospitals, chiropractic clinics, prisons, and private CT screening, to cover all radiology practice performed outside the NHS. Mammography screening, which is not recorded on KH12 returns, was also covered by this survey. For the purposes of this report, all these numbers were added to the numbers for NHS hospitals for the corresponding types of examination, to provide the total number for each of the 231 types of examination, performed both inside and outside the NHS.

2.2 Estimation of typical effective doses

For the previous detailed collective dose estimate (Hart and Wall, 2002) effective doses were calculated on the basis of the tissue weighting factors in ICRP Publication 60 (ICRP, 1991). The recommended tissue weighting factors for effective dose have now changed with the publication of the new ICRP Publication 103 Recommendations (ICRP, 2007). For this report, effective doses have been calculated using the ICRP 103 weighting factors (E_{103}) and also using ICRP 60 (E_{60}) so that a direct comparison could be made with the previous collective dose estimate. The old (ICRP, 1991) and new (ICRP, 2007) tissue weighting factors are compared in Table 2. In particular the weighting factor for the gonads has decreased, and the weighting factors for the breasts and the remainder organs have increased. Furthermore, organs have been introduced that did not formerly have weighting factors, such as the salivary glands, the oral mucosa and the prostate (the latter two now being included in the remainder tissues).

Typical effective doses (both E_{60} and E_{103}) were attributed to each of the 231 distinct and identifiable types of X-ray examination found in the frequency survey. To do this, estimates of the effective dose for each examination were obtained from a number of sources, the predominant one being the 2005 version of the National Patient Dose Database (Hart et al, 2007), using appropriate conversion coefficients to calculate both E_{60} and E_{103} effective doses from the recorded dose quantities. Computed tomography

(CT) examinations are not stored in the NPDD but these were covered by the 2003 NRPB survey of CT doses in the UK (Shrimpton et al, 2005) and other sources.

TABLE 2 Tissue weighting factors according to ICRP 1990 and 2007 recommendations

Organ or tissue	ICRP tissue weighting factors		
	ICRP 60	ICRP 103	103/60
Gonads	0.20	0.08	0.4
Bone marrow	0.12	0.12	1.0
Lower large intestine	0.12	0.12	1.0
Lung	0.12	0.12	1.0
Stomach	0.12	0.12	1.0
Bladder	0.05	0.04	0.8
Breast	0.05	0.12	2.4
Liver	0.05	0.04	0.8
Oesophagus	0.05	0.04	0.8
Thyroid	0.05	0.04	0.8
Bone surface	0.01	0.01	1.0
Skin	0.01	0.01	1.0
Brain		0.01	
Salivary glands		0.01	
Remainder organs*	0.05	0.12	

* ICRP Publication 60 (1991) = adrenals, brain, kidney, muscle, pancreas, small intestine, spleen, thymus, upper large intestine and uterus.

* ICRP Publication 103 (2007) = adrenals, extrathoracic region, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate, small intestine, spleen, thymus and uterus.

More than 300 types of examination were stored in the National Patient Dose Database for the 2005 review, and there were 288,000 dose values, collected from 316 hospitals. This may be compared with 233,000 dose values in the combined 1995 and 2000 reviews which were used in the previous detailed estimate of population dose published in NRPB-W4 (Hart and Wall, 2002).

Doses are recorded in the National Patient Dose Database as entrance surface dose (ESD) values for individual radiographs and dose–area product (DAP) values either for individual radiographs or for complete examinations. The ‘typical’ dose for a specific radiograph or examination was derived from the standard data selection procedure used for the 2000 and 2005 reviews. That is, using data where the mean patient weight for a room was in the range 65 to 75 kg or, if the patient weights were unknown, where there was a minimum of 10 patients per room. This selection procedure retains more than 80% of the data while ensuring that they are representative of a ‘typical’ adult patient. The typical dose was taken to be the mean dose for each examination recorded in the National Patient Dose Database for the 2005 review (Hart et al, 2007). 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.

Effective doses (both E_{60} and E_{103}) have been calculated (Wall et al, 2010) for 24 types of radiograph, 14 radiographic examinations, and 5 fluoroscopic examinations, from typical ESD and DAP values in the National Patient Dose Database using the Finnish Monte Carlo program PCXMC 2.0 [STUK, Helsinki, June 2008]. For each radiograph and examination, the X-ray spectrum (as determined by tube voltage and filtration) was matched to the average values seen in the 2005 review of the NPDD.

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 five trusts was undertaken to determine the types and number of projections typically used for common radiographic examinations. The results are shown in Table 3. Most commonly, all of the trusts in the sample used the same set of projections, though in a few cases one trust had a different protocol to the rest.

TABLE 3 Typical projections for solely radiographic examinations

	Projection		
Examination	AP	PA	LAT
Abdomen	1	–	–
Ankle	1	–	1
Cervical spine	1	–	1
Chest	–	1	–
Femur	1	–	1
Foot	1		1
Head (skull)	1	1	1
Hip	1	–	--
*IVU	3 KUB, 2 kidneys		
Knee	1	–	1
Lumbar spine	1	–	1
Pelvis	1	–	–
Shoulder	1		1 (axial)
Thoracic spine	1	–	1

*IVU = intravenous urography; KUB = kidneys, ureters, bladder.

For three common complex examinations involving radiography and fluoroscopy (barium enemas, barium follow-throughs and barium swallows), a further small survey of ten hospitals was conducted to determine the typical projections used in the UK. There was more variation in the protocols used for each of these barium studies than was found for solely radiographic examinations. Nevertheless there was an underlying consistency, especially when considering what projections were used, and ignoring the order in which the projections were used (which is irrelevant to the total dose). These typical projections were then modelled using PCXMC to estimate the total effective dose (both E_{60} and E_{103}) for the complete examination. Typical protocols currently used at major

hospitals in London, Glasgow and Edinburgh for coronary and femoral angiography were also modelled using PCXMC to estimate their effective doses (Wall et al, 2010).

Effective doses for six common CT examinations were derived from the 2003 NRPB survey of UK CT practice (Shrimpton et al, 2005) but modified by recent Monte Carlo modelling to give values for E_{60} and E_{103} using a mathematical hermaphrodite adult phantom developed at the HPA (Jansen et al, 2009). Data from outside the UK was used for less common CT examinations, with due reference to their source.

For some examinations, conversion coefficients have not been specifically calculated using PCXMC. Table 4 indicates how suitable conversion coefficients were estimated for 3 examinations, by comparison with existing conversion coefficients for similar examinations.

TABLE 4 Derivation of non-standard conversion coefficients for assessing effective doses for three particular types of examination

Examination		E/DAP [mSv/(Gy cm^z)]	Comments
Arthrography		0.12	Average of hip AP and knee AP
Skeletal survey		0.09	Average of arms, legs, skull LAT, lumbar spine LAT, chest AP, abdomen/ pelvis AP
Whole spine/ scoliosis:	AP/PA	0.22	Average of thoracic & lumbar spine AP
	Whole exam	0.16	Average of cervical, thoracic and lumbar spine (AP + lateral)

Dose data from the published literature were used for 21 types of non-CT examination not included in the National Patient Dose Database.

It was verified that the effective dose estimates were consistent between similar examinations – for instance, that the dose for an X-ray of the hand was similar to that for the wrist.

3 RESULTS

3.1 X-ray examination frequencies in NHS hospitals

Table 5 lists the 29 trusts which contributed data for this frequency survey. 16 trusts provided data for the calendar year 2008. Eight trusts provided data for the financial year 2007/08. Five trusts provided data for the financial year 2008/09. All the data were combined and used to represent 2008.

A total of 3,808,623 X-ray and CT examinations were included in the sample for this survey, compared with 3,470,616 in the 1997/98 survey sample (Tanner et al, 2000). By comparing with the KH12 returns reported for the West Midlands and South West regions as a whole, it was found that 77% of all X-ray and CT examinations performed in NHS hospitals in the two regions in 2008 were included in this sample. By comparing

with the KH12 returns for England as a whole, it was found that the survey covered about 15% of all NHS X-ray examinations in England in 2008. The X-ray and CT examinations included in this survey were divided into 231 distinct types of examination, compared with 150 types in the 1997/98 survey. This was done mainly with the aim of producing a more accurate estimate of collective dose.

TABLE 5 Trusts contributing data to survey sample

West Midlands SHA
Birmingham Children's Hospital NHS Foundation Trust
Dudley Group of Hospitals NHS Trust
George Eliot Hospital NHS Trust
Heart of England NHS Foundation Trust
Hereford Hospitals NHS Trust
Mid-Staffordshire General Hospitals NHS Trust
North Staffordshire Hospital NHS Trust
Robert Jones & Agnes Hunt Orthopaedic & District Hospital NHS Trust
Shrewsbury & Telford Hospital NHS Trust
South Warwickshire General Hospitals NHS Trust
The Royal Orthopaedic Hospital NHS Foundation Trust
University Hospital Birmingham NHS Foundation Trust
University Hospital of Coventry and Warwickshire NHS Trust
Walsall Hospitals NHS Trust
Worcestershire Acute Hospital NHS Trust
South West SHA
Dorset County Hospital NHS Foundation Trust
Gloucestershire Hospitals NHS Foundation Trust
North Bristol NHS Trust
Northern Devon Healthcare NHS Trust
Poole Hospital NHS Trust
Royal Cornwall Hospital NHS Trust
Royal Devon and Exeter NHS Foundation Trust
Royal National Hospital for Rheumatic Diseases NHS Foundation Trust
Royal United Hospital Bath NHS Trust
South Devon Healthcare NHS Foundation Trust
Swindon & Marlborough NHS Trust
The Royal Bournemouth & Christchurch Hospitals NHS Foundation Trust
United Bristol Healthcare NHS Trust
Yeovil District Hospital NHS Foundation Trust

Table 6 shows the number of examinations included in the sample for this survey and the percentage frequencies for each of 231 different types of examination, listed in alphabetical order. The same percentage frequencies will be assumed to apply to the totality of X-ray examinations performed in all NHS trusts in the UK in 2008. The final column of the table shows the percentage frequencies seen in the previous survey for 1997/98 (Tanner et al, 2000) for those types of examination which are directly comparable.

TABLE 6 Number of examinations in 2008 survey sample and comparison with relative frequencies from previous survey for 1997/98

Examination Name	Number in sample from 2 regions	Percentage of total sample		
		This survey		Previous survey
Abdomen	145,892	3.831		4.5
Acromio-clavicular joint	1,025	0.027		
Acromio-clavicular joints	550	0.014		
Angiogram general/ abdomen	493	0.013		0.05
Angiogram aortogram	203	0.005	)	0.04
Angiogram abdominal aortogram	112	0.003	)	
Angiogram arch aortogram	639	0.017	)	
Angiogram carotid	84	0.002		
Angiogram cerebral	923	0.024		0.044
Angiogram femoral lower limbs	3,771	0.099		
Angiogram mesenteric artery	135	0.004		
Angiogram pulmonary	142	0.004		0.02
Angiogram renal	314	0.008		
Angiogram upper limb	87	0.002		
Angioplasty	2,025	0.053		
Angioplasty femoral	1,415	0.037		
Angioplasty iliac	889	0.023		
Ankle	135,648	3.562		
Ankle (both)	3,835	0.101		
Antegrade pyelogram	22	0.001		
Arthrogram	2,544	0.067		0.029
Arthrogram shoulder	1,355	0.036		
Barium enema	27,599	0.725		1.3
Barium follow through	5,277	0.139		0.15
Barium meal	2,462	0.065		0.36
Barium small bowel enema	595	0.016		
Barium swallow	11,583	0.304	)	0.46
Barium swallow + meal	2,056	0.054	)	
Barium Video swallow	1,610	0.042		
Biliary drainage	409	0.011		
Biliary intervention & stenting	457	0.012		
Biopsy	710	0.019	)	0.1
liver transjugular	175	0.005	)	
Lung	2	0.000	)	
pathological specimen	977	0.026	)	
small bowel	1	0.000	)	
venous sampling	20	0.001	)	
Bone densitometry DXA	34,527	0.907		0.11
Bronchial stent	7	0.000		
Bronchogram	49	0.001		
Calcaneum	9,010	0.237		

Calcaneum (both)	578	0.015		
Cardiac interventional	539	0.014		
Cardiac pressure line	236	0.006		
Cervical spine	64,775	1.701		3.0
Chest	1,066,106	27.992		30.3
Chest & abdomen (paediatric)	7,919	0.208		
Cholecystostomy	48	0.001		
Clavicle	13,017	0.342		
Clavicle (both)	82	0.002		
Colonic stent	19	0.000		
Colonic transit study	293	0.008		
Colorectal stent	148	0.004		
Coronary angiography	23,961	0.629		0.6
Coronary graft angiography	334	0.009		
Coronary stenting	9,696	0.255		
CT Abdomen	31,574	0.829		1.09
CT Abdomen & pelvis	38,311	1.006		
CT Angiogram	1,775	0.047	)	0.017
CT Angiogram aorta	6,162	0.162	)	
CT angiogram coronary	727	0.019	)	
CT Angiogram lower limbs	573	0.015	)	
CT Angiogram pulmonary	18,737	0.492	)	
CT Angiogram renal/ abdominal	1,246	0.033	)	
CT Angiogram upper limbs	36	0.001	)	
CT bone mineral densitometry	210	0.006		0.007
CT Chest	34,633	0.909		0.69
CT Chest & abdomen	17,199	0.452		
CT Chest & abdomen & pelvis	46,569	1.223		
CT Chest high resolution	11,579	0.304		
CT Colonoscopy (virtual)	3,916	0.103		
CT Enteroclysis	879	0.023		
CT Extremity	8,616	0.226		0.06
CT Head	135,979	3.570		2.23
CT Interventional	2,887	0.076		0.05
CT KUB	6,467	0.170		
CT Liver	1,563	0.041		
CT Liver triple phase	566	0.015		
CT Neck	5,804	0.152		0.092
CT Pelvis	10,975	0.288		0.52
CT Spine cervical	6,080	0.160	)	0.23
CT Spine lumbar	3,445	0.090	)	
CT Spine thoracic	1,113	0.029	)	
CT Urogram	4,385	0.115		
CT Venogram	86	0.002		
CT Whole spine	492	0.013		

Cystogram	759	0.020		
Dacryocystogram	216	0.006		
Dental: cephalometry lateral	6,822	0.179		
Dental: cephalometry PA	40	0.001		
Dental: intra-oral up to 2 films	14,700	0.386	)	0.4
Dental: intra-oral > 2 films	455	0.012	)	
Dental: panoramic	65,303	1.715		1.44
Dialysis line	196	0.005		
Drainage	94	0.002		
Elbow	55,153	1.448		
Elbow (both)	696	0.018		
Electrophysiology	575	0.015		
Embolisation	963	0.025		
Embolisation aneurysm	51	0.001		
Embolisation cerebral artery	220	0.006		
Embolisation of testicular vein	173	0.005		
Embolisation of uterine fibroid	233	0.006		
Enteric stent insertion	115	0.003		
ERCP	7,329	0.192		
Facial bones	18,623	0.489		
Femur	30,403	0.798		0.68
Femur (both)	786	0.021		
Fingers	59,889	1.572		
Fistulogram	986	0.026		
Fluoroscopy	5,395	0.142		
Foot	143,070	3.756		
Foot (both)	19,524	0.513		
Foreign body demonstration	3,513	0.092		
Gastric band	386	0.010		
Gastrojejunostomy	23	0.001		
Gastrostomy	294	0.008		
Hand	94,118	2.471		
Hand (both)	19,051	0.500		
Hand & wrist (bone Age)	1,749	0.046		
Herniogram	531	0.014		
Hickman line	3,458	0.091		
Hip	95,248	2.501	)	3.21
Hip (both)	13,925	0.366	)	
Humerus (upper arm)	26,137	0.686		
Humerus (both)	372	0.010		
Hysterosalpingogram	2,597	0.068		
Inferior vena cavogram	34	0.001		
Intravascular foreign body retrieval	40	0.001		
Intravenous cholangiogram	11	0.000		
Intravenous urogram	9,954	0.261		0.63

Jejunostomy	15	0.000		
Knee	212,263	5.573		
Knee (both)	31,720	0.833		
Leg length measurement	3,345	0.088		0.056
Linogram (any venous cath/ line)	338	0.009		
Lithotripsy	87	0.002		
Loopogram gastrointestinal tract	45	0.001		
Loopogram urinary tract	160	0.004		
Lumbar puncture	11	0.000		
Lumbar spine	96,511	2.534		2.9
Lumbo-sacral joint	5,244	0.138		1.15
Mammo stereotactic aspiration/ biopsy	2,686	0.071		
Mammogram (one breast)	14,092	0.370	)	1.25
Mammogram (both)	60,441	1.587	)	
Mandible	6,624	0.174		
Mastoid Both	75	0.002		
Micturating cystourethrogram (MCUG)	1,241	0.033		
Myelogram lumbar/ cervical puncture	663	0.017		0.017
Nasal bones	196	0.005		
Nasogastric feeding tube	884	0.023		
Neck soft tissue	2,730	0.072		0.15
Nephrostogram	856	0.022		
Nephrostogram (both)	213	0.006		
Nephrostomy	1,501	0.039		
Nephrostomy (both)	163	0.004		
Nerve root injection(spine)	7,072	0.186		
Oesophageal dilatation	291	0.008		
Oesophageal stent	519	0.014		
Operative cholangiogram	630	0.017		
Orbits	4,510	0.118		
Orthopaedic pinning hip	1,920	0.050		
Orthopaedic pinning hip (both)	13	0.000		
Orthopaedic pinning lower limb	4,754	0.125		
Orthopaedic pinning lower limb (both)	9	0.000		
Orthopaedic pinning upper limb	3,647	0.096		
Orthopaedic pinning upper limb (both)	19	0.000		
Other interventional	6,518	0.171		
Pacemaker permanent	4,764	0.125		
Pacemaker Temporary	517	0.014		
Paranasal sinuses	2,238	0.059		
Pelvis	174,518	4.582		3.4
Percutaneous nephrolithotomy	377	0.010		
Percutaneous pancreatogram	4	0.000		
Percutaneous transhepatic cholangiogram	731	0.019		
Pouchogram	49	0.001		

Proctogram	911	0.024	
Pulmonary artery pressures	10	0.000	
Pyeloplasty percutaneous	6	0.000	
Pyeloplasty retrograde	34	0.001	
Radius & ulna	30,555	0.802	
Radius & ulna (both)	179	0.005	
Rectal stent	19	0.000	
Retrograde ureteropyelogram	894	0.023	
Retrograde ureteropyelogram (both)	58	0.002	
RFCC Ablation	994	0.026	
Right heart study	740	0.019	
Sacrolliac joint Both	2,217	0.058	
Sacrum & coccyx	2,113	0.055	
Scapula	1,413	0.037	
Scapula (both)	9	0.000	
Shoulder	99,879	2.622	2.79
Shoulder (both)	3,453	0.091	
Sialogram	1,377	0.036	
Sinogram	184	0.005	
Skeletal survey	2,782	0.073	0.043
Skull	6,334	0.166	3.7
Stent graft aorta	343	0.009	
Sternoclavicular joint (both)	673	0.018	
Sternum	2,385	0.063	
Superior vena cavogram	36	0.001	
Temporomandibular joint	246	0.006	
Temporomandibular joint (both)	539	0.014	
Thoracic inlet	323	0.008	
Thoracic spine	27,519	0.723	1.0
Thoracolumbar spine	4,148	0.109	
Thrombolysis	185	0.005	
Thumb	32,270	0.847	
Thumb (both)	812	0.021	
Tibia & fibula	40,779	1.071	
Tibia & fibula (both)	593	0.016	
TIPS Shuntogram	28	0.001	
TIPS Stent insertion	86	0.002	
Toes	18,390	0.483	
T-tube cholangiogram	580	0.015	
Ureteric stent	1,810	0.048	
Ureteric Stent (both)	162	0.004	
Urethral stent	43	0.001	
Urethrogram	311	0.008	
Urodynamics	759	0.020	
Valvuloplasty	48	0.001	

Vascular stent	1,424	0.037	
vena cava filter	275	0.007	
Venacavogram	1	0.000	
Venogram limb	1,516	0.040	
Venogram torso	266	0.007	
Vertebroplasty	180	0.005	
Wada study	4	0.000	
Whole Spine (scoliosis)	4,862	0.128	0.12
Wrist	159,198	4.180	
Wrist (both)	4,290	0.113	
Total	**3,808,623**	**100**	**62.7**

One of the distinct changes in relative frequencies since our previous survey is that CT now comprises 11% of all hospital X-ray examinations, whereas in 1998 it comprised 5%. This change is partly due to the increased use of CT for scanning more than one section of the torso at a time (that is, chest, abdomen or pelvis). It is also due to increased use of CT angiography, CT of the urinary system and CT of the head. This figure of 11% is a slightly lower percentage than given by the KH12 returns (12%). A minority of NHS Trusts submitted data to this survey with a different method of counting CT examinations, which was amended for this report. If these, or other, Trusts also use the same method of counting for their KH12 returns, there will be a slight difference between the 2 types of data. For instance, a 'CT chest & abdomen & pelvis' which is performed in one scan would be counted by some trusts as 3 examinations, whereas for this survey it is counted as one examination. This approach has also been followed in this report for other examinations such as 'CT abdomen & pelvis' and 'CT chest & abdomen', each of which has also been classed as one examination and not two. [This multiple counting by some trusts also applied to 16 conventional X-ray examinations of more than one anatomical region, for example, both hands, both feet, both breasts. It was clear when trusts had double- or triple-counted their RIS data because the output was headed as 'Summed' rather than 'Counted'. Also, the total number for each X-ray examination of two anatomical regions, and for 'CT abdomen & pelvis' and 'CT chest & abdomen' was always divisible by two. Totals for 'CT chest & abdomen & pelvis' were always divisible by three. Trusts that had triple-counted their CT chest & abdomen & pelvis clearly had many more of such examinations than other trusts.]

Examinations other than CT that have also increased in frequency are bone densitometry (up from 0.1% to 0.9%), interventional procedures (0.9% to 1.4%) and mammography (1.25% to 2%). Some examinations that have decreased in frequency are barium meals (down from 0.36% to 0.06%), barium enemas (1.3% to 0.7%), IVUs (0.6 to 0.3%), skull (3.7% to 0.2%) and spine (cervical, lumbar & thoracic; 8% to 5%). Skull radiography has diminished considerably since the publication of guidance from the National Institute for Health and Clinical Excellence (NICE) on the investigation of head injury, which stated that the use of CT imaging was associated with better outcomes (NICE, 2007).

Table 7 shows the percentages in the samples from each region for some examinations that are major contributors to collective dose (or have been in the recent past). It can be

seen that any differences between the 2 regions are minor. This gives confidence that the overall sample (combining the 2 regions) is probably representative of the national situation.

TABLE 7 Percentages for various types of examination in each regional sample

Examination	West Midlands	South West
Chest	28.04	27.94
Cervical spine	1.72	1.68
Thoracic spine	0.71	0.73
Lumbar spine	2.63	2.43
Mammography	1.92	2.00
Abdomen	4.16	3.45
Pelvis	4.74	4.41
Barium meal	0.09	0.04
Barium enema	0.63	0.83
Barium follow	0.12	0.16
IVU	0.21	0.32
Cardiac angiography	0.69	0.56
CT head	3.74	3.37
CT neck	0.16	0.14
CT spine	0.33	0.26
CT trunk	3.46	3.02
PTCA	0.29	0.21

According to the KH12 returns there was a total of 26 million X-ray examinations of all type conducted in hospitals in the English NHS in 2008/09 (Department of Health, 2009). For Northern Ireland, Scotland and Wales there is no equivalent to the English KH12 returns for 2008. Extrapolating the number of English X-ray examinations to the UK as a whole simply on the basis of the relative populations gives a figure of 31 million X-ray examinations in NHS hospitals in the UK. (England's population was 51.5 million in 2008 and the population of the UK was 61.4 million (www.statistics.gov.uk).)

3.2 X-ray examination frequencies outside NHS hospitals

3.2.1 General dental practice

Some dental X-ray examinations (intra-oral, panoramic & cephalometric) are performed in NHS hospitals and are included in the analysis above, but the majority of dental radiography is conducted in primary care dental surgeries by general dental practitioners. Most of these radiographs are performed under the NHS system, for which statistics are available, but some are provided as private practice. During the financial year 2008/09, 9 million dental radiographs on adults and children were taken in the English NHS by primary care dentists and 440,000 in the Welsh NHS (NHS Information Centre, 2009). For both England and Wales, the number of such radiographs taken had fallen by more than 33% since the financial year 2003/04. During 2008/09, 1.28 million

dental radiographs were taken in Scotland (Scottish Dental Practice Board, 2009) and for Northern Ireland the corresponding number was 290,000 (Northern Ireland Business Services Organisation, 2009). Together these give a total of 11 million dental radiographs performed by general dental practitioners in the UK NHS.

Table 8 shows the number of panoramic and intra-oral radiographs taken in the NHS in England and Wales from 1992 to 2005 (http://www.nhsbsa.nhs.uk/DentalServices/2870.aspx). The total number of radiographs peaks at 15.4 million in 2000/01 and then declines. The proportion of panoramic radiographs peaked in the same year (2000/01) at 14% and in the latest year with such detailed statistics (2004/05) was 13%. (NB This appears to differ radically from the proportion (23% panoramic) used in the 1997/98 frequency survey (Tanner et al, 2000) only because that was as a proportion of **examinations**, each of which might include several radiographs.) We have used 13% for the proportion of radiographs that were panoramic in 2008.

TABLE 8 Annual numbers of NHS dental radiographs in England & Wales

Year	Panoramic	Intra-oral & cephalometric	Total number of radiographs	% panoramic
1992/93	1,425,293	13,496,053	14,921,346	9.6
1993/94	1,443,959	12,818,748	14,262,707	10.1
1994/95	1,515,477	12,794,298	14,309,775	10.6
1995/96	1,615,264	12,780,631	14,395,895	11.2
1996/97	1,707,187	12,498,703	14,205,890	12.0
1997/98	1,871,995	12,673,311	14,545,306	12.9
1998/99	2,029,268	12,956,289	14,985,557	13.5
1999/00	2,074,155	12,869,573	14,943,728	13.9
2000/01	2,196,700	13,220,379	15,417,079	14.2
2001/02	2,121,707	13,156,930	15,278,637	13.9
2002/03	1,998,840	12,936,400	14,935,240	13.4
2003/04	1,976,306	13,072,644	15,048,950	13.1
2004/05	1,809,809	11,821,687	13,631,496	13.3

In our previous frequency survey (Tanner et al, 2000) it was estimated that 25% of dental patients paid privately and not through the NHS. This was probably still the case in 2002, since a survey by healthcare analysts, Laing and Buisson, found that a quarter of UK dental patients were paying privately for their care (BBC, 2003). The report said that “Since our last survey in 1998, the proportion of patients paying privately for dental care has remained relatively unchanged”. During 2000/01 there are therefore likely to have been about 5.1 million radiographs taken in private practice in England & Wales (that is 25% of a total of 20.5 million radiographs in the NHS and private practice combined).

Table 8 shows that over the period 1992 to 2003 there was a fairly constant total for the number of radiographs in the NHS. But there appears to have been a decline in NHS radiographs between 2003/04 and 2008/09 (from 15 million to 9.4 million in England &

Wales). It is likely that this was due to a transfer of dental work away from the NHS and into private practice. We have assumed that the total number of radiographs taken in the NHS and private practice has remained approximately constant, at 20.5 million dental radiographs per year. This means that in 2008, in addition to the 11 million dental radiographs taken by dental practitioners in the UK NHS, about 9.5 million radiographs would have been taken in private practice, which is 46% of the total of 20.5 million.

Is it reasonable to assume that the number of dental X-rays has remained constant? Growth in the UK population might lead to a growth in the number of dental X-ray examinations, but in the past this has been a minor factor. Over the last 30 years the growth in population has only been around 0.5% per year. Another relevant point is that data from the United Nations Scientific Committee on the Effects of Atomic Radiation indicate that the frequency of dental X-ray examinations per 1000 population has been decreasing for Health Care Level I countries over the period 1984-2007 (Table B53, UNSCEAR, 2010). It is therefore possible that the annual total number of dental X-rays in the UK could have decreased from 2001-2008. Our assumption of constant number of dental X-rays is thus a compromise between a possible increase and a possible decrease. The collective dose from dental X-rays is anyway small (less than 0.5 % of the total for all medical X-rays), so the effect of this assumption on the total collective dose will also be small.

We therefore estimate that 20.5 million dental radiographs are taken per year in general dental practice in the UK. 13% of these (2.7 million) are estimated to be panoramic radiographs.

The estimated number of dental X-ray examinations in the UK is 11.7 million based on an average of 1.75 radiographs per examination across intra-oral and panoramic procedures (NHS Information Centre, 2009). This is similar to the figure of 1.78 radiographs per examination used in the previous frequency survey (Tanner et al, 2000).

3.2.2 Independent hospitals

The Health and Social Care Yearbook for 2008/09 (Binley's, 2008) lists 274 independent hospitals in the UK. The Yearbook provides information on whether these have X-ray facilities for only a small fraction of these hospitals. For the 1997/98 frequency survey it was found that 70% of independent hospitals had X-ray facilities. Currently BMI Healthcare (which runs the largest number of independent hospitals in the UK) has X-ray facilities at about 70% of its hospitals (www.bmihealthcare.co.uk). Assuming therefore that 70% of all independent hospitals had X-ray facilities in 2008 leads to an estimate of 192 independent hospitals with X-ray facilities in the UK.

In general, larger hospitals perform a greater number of X-ray examinations than smaller hospitals. We have used the number of beds at each hospital as an approximate measure of the hospital size. Independent hospitals with X-ray facilities have an average of 50 beds, so there are a total of about 9600 beds in such hospitals. The total number of beds in all the trusts in our NHS frequency sample is 21,371, which, for a total of 3,808,623 examinations in our NHS frequency survey, gives 178 examinations per bed. If independent hospitals had a similar radiology workload per bed to those in the NHS, it can be calculated that there would be 9,600 X 178 = 1.7 million X-ray examinations performed in independent hospitals. However, the radiology workload per bed would

not be as high as an NHS hospital because independent hospitals do not deal with any acute trauma patients and would have fewer GP referrals and fewer oncology follow-up patients. We estimate around a 30% reduction in workload per bed compared with an NHS site. Therefore we estimate 1.2 million X-ray examinations were taken in independent hospitals in 2008. This is about 40% higher than the estimate for the 1997/98 survey; the increase arises from the assumption that the radiology workload per bed in independent hospitals is almost as high as the NHS as a whole, whereas previously we assumed that independent hospitals only had a radiology workload similar to small NHS hospitals (92 examinations per bed in 1998).

3.2.3 Mammography screening

The data on mammography in Table 6 relate only to symptomatic women whose referrals were made directly to the imaging department in NHS hospitals. Procedures undertaken as part of the NHS Breast Screening Programme are excluded from KH12 returns and were not included in our frequency survey. Whereas symptomatic mammography is included in the Radiology Information System (RIS), screening mammography is not included in the RIS, instead it is recorded in the National Breast Screening information System (NBSS).

Figures from the Breast Screening Programme review for 2008 indicate that 1.94 million women underwent mammography screening in the UK, and 90,000 were recalled for further assessment (NHS Breast Screening Programme, 2008). This total figure of 2.03 million examinations has increased by 45% over the figure in our previous frequency survey of 1.4 million for 1997/98 (Tanner et al, 2000). The main factor for this increase has been the widening of the age range invited for screening. The age range had been 50-64 years old, but was increased to 50-70 years old from 2004.

3.2.4 Ministry of Defence

The Ministry of Defence formerly operated its own service hospitals, but no longer does so. Currently the MoD is a part-user of hospitals that are within NHS Trusts. These include Derriford Hospital, Friarage Hospital, Frimley Park Hospital, Peterborough Hospital, Royal Hospital Haslar, and Selly Oak Hospital. Any X-ray examinations performed for the MoD at these hospitals should be included in the NHS statistics (KH12 returns). Therefore for the purposes of this report there is no need to estimate the number of medical X-ray examinations carried out on behalf of the MoD.

However, the Ministry of Defence does run the Defence Dental Services (DDS), which performs dental x-ray examinations on military personnel in the UK and overseas. The DDS took 164,000 intra-oral and 1354 panoramic radiographs in the UK in 2008 (Stephen Smith, Radiation Physics Team, DSTL, personal communication). Typically about two intra-oral radiographs are taken per examination, so this amounts to 82,000 intra-oral examinations and 1350 panoramic examinations.

3.2.5 Chiropractic clinics

There are currently more than 2,000 practising chiropractors in the UK (BCA, 2009; GCC, 2004; and www.yell.com). About 35% of chiropractors in the UK have their own X-ray facility (GCC, 2004), the rest refer their patients to a hospital. The hospital X-ray examinations have already been counted by this survey. X-ray films are usually only taken at a patient's first visit. Each of the 700 chiropractors with their own X-ray facility receives on average 5 new patients per week (GCC, 2004). Of these patients typically

50% receive an X-ray examination (GCC, 2004), which means that there would have been 87,500 X-ray examinations performed in chiropractic clinics in 2008. (Thus each chiropractor with an X-ray facility performs an X-ray examination on an average of 125 patients per year; these are mostly radiographs of the spine.) This estimate is not radically different to the estimate of 75,000 chiropractic X-ray examinations in the 1997/98 survey, but it is based on firmer data (three different, but similar, estimates of the number of practising chiropractors; and better information on chiropractic practice from the General Chiropractic Council). The division of chiropractic X-ray examinations between different anatomical areas is thought to be about 60% lumbar spine, 30% cervical spine, 5% thoracic spine, and 5% extremities (as assumed by Tanner et al, 2000). This division has been used in allocating the different types of chiropractic examination a specific radiation dose for the purpose of the collective dose estimate.

3.2.6 Prisons

There are about 140 prisons in England and Wales with a prisoner population of about 85,000 (www.hmprisonservice.gov.uk). About 130 of these prisons have dental X-ray equipment, but only about 25 have medical X-ray equipment, which would typically be used to search for a fracture of a limb. A typical dental X-ray workload is about 200 examinations per year per prison (Sharon Ely, HPA, Occupational Services Department, personal communication). So across all the prisons with dental X-ray equipment, there would be about 26,000 examinations/ year. A typical workload for a prison with medical X-ray equipment is about 300 medical X-ray examinations per year (Sharon Ely, personal communication), leading to an estimate of about 7,500 examinations/ year in England and Wales. Scaling up to the UK on the basis of total population leads to a total of 31,000 dental and 9,000 medical X-ray examinations per year.

For the 1997/98 frequency survey there were estimated to be 12,000 medical X-ray examinations and 22,000 dental X-ray examinations in UK prisons. At that time there were 115 prisons with dental X-ray equipment and 40 prisons with medical X-ray sets in England & Wales, and the prison population of England and Wales was about 61,000. An estimate of the current number of X-ray examinations can also be made by extrapolating to 2008 on the basis of the increased prison population and the decreased number of medical X-ray sets. Since the prison population has increased by about 40%, one would expect about 31,000 dental X-ray examinations per year in the UK. Medical X-ray examinations would similarly have risen to 17,000 per year, but the number of X-ray sets has diminished by about 40%. Therefore one would expect about 12,000 medical X-ray examinations to have been performed in UK prisons in 2008. Since the 2 methods give similar estimates, we feel justified in assuming about 10,000 medical X-ray examinations and 31,000 dental X-ray examinations per year in UK prisons.

3.2.7 Personally initiated CT scans

A practice which is currently significant but was not common at the time of the previous frequency survey is personally initiated CT scans for the health assessment of asymptomatic individuals. Some private hospitals carry out health checks, but any X-ray imaging done as a part of these health checks has been accounted for in section 3.2.2 on independent hospitals. However in 2008, at least four organisations, Lifescan (www.lifescanuk.org), Prescan (www.prescan.co.uk), the European Scanning Centre (www.europeanscanning.com), and 3FiveTwo (www.3fivetwo.com), routinely used CT scanners for asymptomatic health assessment. The Committee on Medical Effects of

Radiation in the Environment (COMARE, 2007) has recommended that providers of CT scanning services should not offer asymptomatic individuals CT scanning of the whole-body or the whole-torso, or of the lung. Neither should they offer CT scanning for spinal conditions, osteoporosis or body fat assessment. Lifescan, Prescan, the European Scanning Centre and 3FiveTwo offered examinations such as CT coronary angiography, CT calcium scoring of the coronary arteries, and virtual colonoscopy as a form of health check. Lifescan had CT scanners at 7 locations across England and Scotland. Prescan had a CT scanner at its City of London Medical Centre. The European Scanning Centre had an electron beam CT scanner at its premises in Harley Street, London. 3FiveTwo had a 64 slice CT scanner at its premises in Belfast, Northern Ireland. If these 10 scanners had a similar workload to those in the English NHS, they might be performing 80,000 scans per year. This is based on 400 CT scanners in England (Kim Stonell, HPA, personal communication) performing 3,355,000 scans in 2008/09 (Department of Health, 2009). However it is probable that the 10 scanners were doing much less than this, and 20,000 scans would be a more likely estimate. For the purpose of the collective dose estimate, we have assumed that 40% of these scans were CT coronary angiography, 40% were CT virtual colonoscopy and 20% were calcium scoring.

3.3 Total X-ray examination frequencies in the UK

The frequency of X-ray examinations from all health care sectors in the UK in 2008 is shown in Table 9.

TABLE 9 Frequency of X-ray examinations in the UK in 2008

Sector	Number of examinations (1000s)	Percentage of total (%)	Number per 1000 population
NHS Trusts	30,963	67.2	504
Independent hospitals	1,200	2.6	19.5
Mammography screening	2,030	4.4	33.1
Chiropractic clinics	88	0.2	1.4
Prisons (excluding dental)	10	0.02	0.2
Private CT screening	20	0.04	0.3
Total (excluding dental practice)	34,311	74	559
Dental (primary care + prisons + MoD)	11,828	26	193
Total (all UK medical and dental)	46,139	100	752

The total number of all types of medical and dental X-ray examination in the UK, both inside and outside the NHS, is estimated to be about 46 million in 2008, a 10% increase over 1997/98. NHS hospitals perform 67% of these examinations and about 26% are carried out by dentists in primary care. 752 X-ray examinations of all type are carried out each year per thousand head of population. Medical X-ray examinations, excluding those undertaken by dentists in primary care but including dental examinations performed in hospitals, are carried out 559 times per year per thousand population.

3.4 Typical effective doses for X-ray examinations in the UK

Table 10 shows typical values of E_{60} for the 24 radiographs that were modelled using PCXMC to derive an effective dose, based on the average of typical ESD and DAP

measurements from the 2005 review (Hart et al, 2007). Table 10 also shows the corresponding E_{60}/ ESD and E_{60}/ DAP coefficients (Wall et al, 2010) and, for comparison, the conversion coefficients that were used for the previous estimate of collective dose that was calculated in NRPB-W4 (Hart and Wall, 2002). This comparison shows that the conversion coefficients are generally very similar. Only cervical spine LAT, femur AP, knee and foot exhibit significant differences, by factors in the range of 3 to 8. For femur, knee and foot, the differences arise because the conversion coefficients were very roughly estimated for NRPB-W4 (Hart and Wall, 2002) but are thought to be improved in accuracy this time from the PCXMC modelling. Overall, the differences between the conversion coefficients will not significantly alter the collective dose.

TABLE 10 Effective doses and conversion coefficients based on ICRP 60

Projection	E_{60} * (mSv)	PCXMC E_{60} /ESD (mSv/mGy)	Previous data** E_{60} /ESD (mSv/mGy)	PCXMC E_{60} /DAP (mSv/Gycm^2)	Previous data** E_{60} /DAP (mSv/Gycm^2)
Head AP	0.022	0.014	0.012	0.039	0.038
Head PA	0.016	0.010	0.008	0.028	0.026
Head Lat	0.012	0.009	0.009	0.028	0.029
Cervical spine AP	0.018	0.036	0.042	0.192	0.220
Cervical spine Lat	0.012	0.022	0.006	0.114	0.031
Shoulder AP	0.007	0.014	0.007	0.063	0.036
Shoulder (axial)	0.005	0.010		0.056	
Chest PA	0.014	0.126	0.102	0.153	0.120
Chest Lat	0.031	0.072	0.080	0.12	0.110
T spine AP	0.218	0.086	0.092	0.224	0.220
T spine Lat	0.148	0.032	0.026	0.093	0.100
L spine AP	0.409	0.122	0.107	0.235	0.220
L spine Lat	0.251	0.032	0.025	0.11	0.100
LSJ Lat	0.209	0.012	0.012	0.097	0.100
Abdomen AP	0.471	0.145	0.136	0.198	0.210
Pelvis AP	0.449	0.156	0.156	0.220	0.230
Single hip AP	0.148	0.078	0.060	0.226	0.175
Both hips AP	0.354	0.118		0.23	
Femur AP	0.024	0.049	0.005	0.077	0.010
Femur Lat	0.002	0.004	0.005	0.0064	0.010
Knee AP	0.0002	0.001	0.005	0.006	0.010
Knee Lat	0.0002	0.001	0.005	0.006	0.010
Foot (dorsi-plantar)	0.0001	0.001	0.005	0.005	0.010
Foot (oblique)	0.0001	0.001	0.005	0.005	0.010

* Effective dose based on average of DAP & ESD measurements from 2005 review of NPDD (and average of left & right laterals)

** Previous data from reports NRPB-R262 (Hart et al, 1994) in black or NRPB-W4 (Hart and Wall, 2002) in blue

Table 11 shows typical values of E_{103} for the 24 radiographs based on the average of typical ESD and DAP measurements from the 2005 review (Hart et al, 2007) and the corresponding E_{103}/ ESD and E_{103}/ DAP coefficients (Wall et al, 2010).

TABLE 11 Effective doses and conversion coefficients based on ICRP 103

Projection	E_{103} (mSv)	E_{103} /ESD (mSv/mGy)	E_{103} /DAP (mSv/Gycm^2)
Head AP	0.033	0.022	0.058
Head PA	0.020	0.013	0.034
Head Lat	0.016	0.012	0.037
Cervical spine AP	0.018	0.035	0.187
Cervical spine Lat	0.012	0.023	0.118
Shoulder AP	0.007	0.015	0.064
Shoulder (axial)	0.004	0.008	0.046
Chest PA	0.014	0.131	0.158
Chest Lat	0.038	0.090	0.125
T spine AP	0.238	0.094	0.244
T spine Lat	0.144	0.031	0.093
L spine AP	0.389	0.116	0.224
L spine Lat	0.211	0.027	0.092
LSJ Lat	0.169	0.009	0.08
Abdomen AP	0.429	0.132	0.180
Pelvis AP	0.284	0.099	0.139
Single Hip AP	0.087	0.046	0.134
Both Hips AP	0.191	0.064	0.13
Femur AP	0.011	0.023	0.036
Femur Lat	0.001	0.002	0.0034
Knee AP	0.0001	0.001	0.0034
Knee Lat	0.0001	0.001	0.003
Foot (dorsi-plantar)	0.0001	0.001	0.0032
Foot (oblique)	0.0001	0.001	0.0032

Typical effective doses for adult patients for 14 complete radiographic examinations are shown in Table 12 (Wall et al, 2010). The final column of this table shows the ratio between E_{103} and E_{60} which gives an indication of where the collective dose is likely to change significantly between estimates based on E_{60} and E_{103}. This ratio is also shown in Tables 13 and 14.

TABLE 12 Typical effective doses for complete radiographic examinations

Examination	E_{60} (mSv)	E_{103} (mSv)	E_{103} / E_{60}
Head (Skull)	0.05	0.068	1.36
Cervical spine	0.03	0.03	1.00
Shoulder	0.012	0.011	0.92
Chest	0.014	0.014	1.00
Thoracic spine	0.37	0.38	1.03
Lumbar spine	0.66	0.60	0.91
Abdomen	0.47	0.43	0.91
Pelvis	0.45	0.28	0.62
Single Hip	0.15	0.087	0.58
Both Hips	0.35	0.19	0.54
Femur	0.022	0.012	0.55
Knee	0.0004	0.0002	0.5
Foot	0.0002	0.0002	1.00
IVU	2.3	2.1	0.91

Typical effective doses for adult patients from X-ray examinations involving fluoroscopy and radiography are shown in Table 13 (Wall et al, 2010).

TABLE 13 Typical effective doses for adult patients from complete X-ray examinations involving radiography and fluoroscopy

Examination	E_{60} (mSv)	E_{103} (mSv)	E_{103} / E_{60}
Barium swallow	1.4	1.5	1.07
Barium follow	1.5	1.3	0.87
Barium enema	3.0	2.2	0.73
Coronary angiography	3.9	3.9	1.00
Femoral angiography	2.8	2.3	0.82

The list of 231 examinations from the frequency survey included 27 CT examinations. Doses for six of these were taken from the 2003 NRPB survey (Shrimpton et al, 2006) modified by recent Monte Carlo modelling at the HPA to give estimates of both E_{60} and E_{103} as summarised in Table 14. Only data from outside the UK were available for the less common CT examinations, thus CT cervical spine, CT bone mineral densitometry and CT extremity doses were taken from surveys in Australia (Heggie et al, 2006), the USA (Mettler et al, 2008; Hawkinson et al, 2007) and Switzerland (Verdun et al, 2008), respectively. An effective dose of 0.6 mSv was reported for CT examinations of the lower limbs in Switzerland and this value has been used for all CT examinations of the extremities in this report. These doses are listed in the Appendix.

TABLE 14 Effective doses for common CT examinations on adult patients

CT examination	E_{60} (mSv)	E_{103} (mSv)	E_{103} / E_{60}
CT Head	1.6	1.4	0.84
CT Chest	5.8	6.6	1.14
CT Chest hi-resolution	1.2	1.2	1.0
CT Abdomen	5.1	5.6	1.09
CT Abdomen + Pelvis	6.8	6.7	0.98
CT Chest + Abdomen + Pelvis	9.2	10	1.09

Estimates of the typical effective dose, derived from data in the 2005 version of the National Patient Dose Database (Hart et al, 2007) and appropriate conversion coefficients, were obtained for 142 examinations. The resulting effective doses, based on ICRP 103 and ICRP 60, are displayed in the Appendix. The number of dose measurements on which the effective dose value was based, and the number of hospitals which had supplied measurements, were both used to establish a reliability rating (A to E) as shown later in Table 16. This information gives some indication of how representative the estimates of effective dose are for national practice.

Dose data from other sources (mainly published surveys) were also added to the Appendix for 21 types of non-CT examination not included in the National Patient Dose Database. Where there was more than one published survey with a mean effective dose for an examination conducted in the UK, the mean of the mean effective doses was taken. If no dose data could be found for a specific examination, an approximate estimate of the effective dose was made by comparison with similar examinations. Such comparative dose estimates covered the remaining 41 examinations.

To give an example of the effective dose calculations in the Appendix, skull examinations typically consist of one PA, one Lateral and one AP radiograph. Using the ESD for each projection, with PCXMC to model each of these projections and adding the three together, results in a total effective dose of 0.043 mSv. Following the same procedure but using the DAP values from the National Patient Dose Database results in a total effective dose of 0.055 mSv. The average of these two estimates (0.05 mSv) has been used as the typical effective dose for a skull examination in the collective dose calculation.

The doses for intra-oral and panoramic dental radiographs have reduced by 40% and 10% respectively in the period between the late 1990s and 2005 (Gulson et al, 2007). The effective doses (E_{60}) that were used for these dental radiographs in NRPB-W4 have therefore been reduced accordingly (to 0.003 mSv and 0.009 mSv for intraoral and panoral examinations, respectively) for use in this collective dose estimate.

The effective doses (E_{103}) for dental X-ray examinations were taken from Ludlow et al (2008); they include the dose to salivary glands as a weighted organ and include the dose to the oral mucosa as a remainder organ. This has had the effect of increasing the effective dose (E_{103}) for intra-oral and panoramic radiography by a factor of two (to 0.005 mSv and 0.019 mSv, respectively) in comparison with our estimates for E_{60}.

The ICRP 60 effective doses for mammography (E_{60}) were derived from the mean glandular dose by multiplying by a breast tissue weighting factor of 0.05. The ICRP 103 effective doses for mammography were derived from the mean glandular dose by multiplying by a tissue weighting factor of 0.12. This is the method that is recommended in the *European guidance on estimating population doses from medical X-ray procedures* (Wall et al, 2008) and is a change from the doubling of the tissue weighting factor that was used previously by Hart and Wall (2002). In the NHS Breast Screening Programme, it used to be the case that women being screened for the first time had two radiographic views taken of each breast, medio-lateral oblique and cranio-caudal, while women being screened on subsequent occasions had just one view taken of each breast. From 2003, all women have had two views taken of each breast in every screening round and not just the first (Young et al, 2005). So the effective doses for breast screening examinations in this report (0.21 mSv E_{60} and 0.5 mSv E_{103}) are based on two views of each breast. 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. It was assumed that women recalled for assessment after screening had, on average, 2.5 films taken (Law, 1995) which was the situation for the previous estimate of collective dose (Hart and Wall, 2002).

Bone mineral densitometry has become a fairly common X-ray procedure, with nearly 300,000 examinations per year in the UK. These are mostly performed using dual energy X-ray absorptiometry (DXA) of the lumbar spine and proximal femur. When the previous estimate of collective dose was made (Hart and Wall, 2002) pencil beam DXA systems were most common, giving a typical effective dose of 2 microsieverts. Currently, fan beam and cone beam systems are in use, which give shorter scan times but higher radiation doses. These are typically of the order of 10 microsieverts (Larkin et al, 2008; Blake, 2003) and the contribution to collective dose is still very small.

Some examinations were not sufficiently well specified for an accurate estimation of the effective dose. For example, there were 48,000 procedures that were simply called ‘fluoroscopy’, with no more specific information given. The effective dose assigned to these (1.6 mSv for both E_{60} and E_{103}) was the average for common fluoroscopy examinations.

The effective dose for fluoroscopy-guided injections was derived from the weighted-average DAP for facet joint injections, hip injections, needle insertion, and general fluoroscopy.

3.5 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 previous NRPB population dose estimate (Hart and Wall, 2002), i.e. the following order: ‘head and neck’, spine, ‘limbs and joints’, chest, angiography, gastrointestinal tract, biliary system, urinary system, gynaecology, bone mineral densitometry, CT and

interventional procedures. The information itemised for each type of examination includes the following:

a total number of examinations performed in 2008 for all sectors of healthcare in the UK,
b typical effective dose E_{60} ,
c typical effective dose E_{103} ,
d source of data for these effective doses,
e reference,
f reliability rating (explained in Section 3.6),
g collective dose for the UK in man Sv (based on ICRP 60),
h collective dose for the UK in man Sv (based on ICRP 103),
i % contribution to the total collective dose (ICRP 103).

The source of information for the dose data is indicated either by naming a country, or by NPDD (meaning the National Patient Dose Database), or by naming the analogous examination(s) from which surrogate 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. This choice was generally based on either the largest sample size or an average of the different doses. A reasonable similarity was found for most of the cases where the effective dose for a complete examination could be calculated from two or more of three different types of data, namely ESD/ projection, DAP/ projection and DAP/ examination.

The frequencies and effective doses for cardiac X-ray procedures (coronary angiography, PTCA and pacemakers) shown in the Appendix were reasonably similar to those presented by Faulkner and Werduch (2008).

For each of the 231 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 on the basis of ICRP 103 are shown in the last two columns of the Appendix.

The change in the breast tissue weighting factor from 0.05 to 0.12 has resulted in a collective dose from mammography which is 2.4 times bigger using E_{103} compared with E_{60}.

The total annual collective dose from all X-ray examinations in the UK in 2008 is shown at the end of the Appendix and amounts to 24,700 man Sv based on ICRP 103. This is a 28% rise over the collective dose for 1997/98. The increase is mainly due to the doubling of the collective dose from CT. It is also partly due to the increased population of the UK, up from 59 to 61 million. However, it can be seen that a small part of the increase (about 2%) is due to the use of the updated definition of effective dose given in ICRP Publication 103, since the estimate for collective dose based on ICRP Publication 60 is 24,250 man Sv. This latter version of collective dose can be directly compared to our previous estimate and amounts to an increase of 5000 man Sv (or 26%) over the collective dose in 1997/98.

With a UK population of 61.4 million in 2008, the collective dose of 24,700 man Sv gives an annual per caput effective dose of 0.4 mSv, compared with 0.33 mSv in 1997/98. Table 15 shows the frequency of broad categories of examination and their contribution to collective dose in the UK, for this estimate and the previous one. CT now contributes around 68% to the total collective dose from X-ray examinations, compared with 40% in 1997/98. Whereas CT contributed about 5% of all hospital X-ray examinations in terms of frequency in 1997/98, in 2008 it contributed 11%. About 250,000 angiography examinations are now performed using CT, with the result that both the number of examinations and collective dose from conventional angiography have fallen over the last 10 years. Over the same period, the number of examinations and the collective dose from interventional procedures have both risen. As a result, conventional angiography now contributes about 5% to collective dose and interventional procedures about 8%. Conventional radiology, although it constitutes 90% of the number of examinations, only contributes around 19% to collective dose. 12% of the collective dose from conventional radiology is now contributed by mammography using ICRP 60, or 28% using ICRP 103, as the basis for estimates of effective dose.

TABLE 15 X-ray examination frequency and collective dose in the UK

Category of examination	Number of examinations		Collective dose (man Sv)		
	1997/98	2008	1997/98	2008 (E_{60})	2008 (E_{103})
Conventional radiology*	39,586,000	41,927,000	7,850	4,695	4,799
CT	1,387,000	3,421,000	7,662	16,302	16,723
Angiography (non-CT)	321,000	293,000	1,923	1,213	1,187
Interventional (non-CT)	247,000	442,000	1,239	2,037	1,985
Total	41,541,000	46,083,000	**19,300	24,247	24,694

* inc. dental

** inc. 626 man Sv from unassignable examinations

Figure 1 shows the percentage contribution to UK collective dose and frequency from the twenty examinations that make the biggest contribution to collective dose (on the basis of ICRP 103). The examinations are arranged in descending order of their contribution to collective dose. The top five examinations are all CT and 12 out of the twenty examinations are CT.

Figure 2 shows the contribution to UK collective dose and frequency from the twenty most frequently performed X-ray examinations. The examinations are arranged in descending order of their frequency. The most common examinations (dental, chest and limbs) make very small contributions to collective dose. With one exception (CT head) CT examinations only reach the lower levels of this diagram.

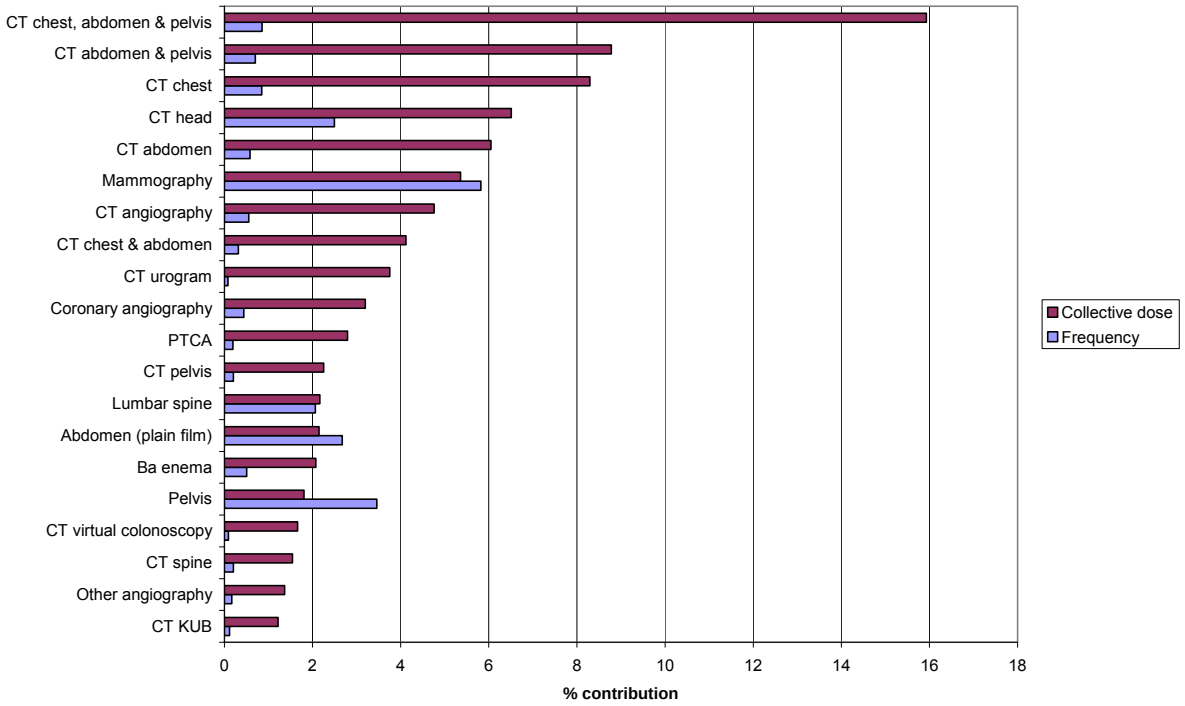

FIGURE 1 Contribution to UK collective dose and frequency from the 20 medical and dental X-ray examinations making the biggest contributions to collective dose

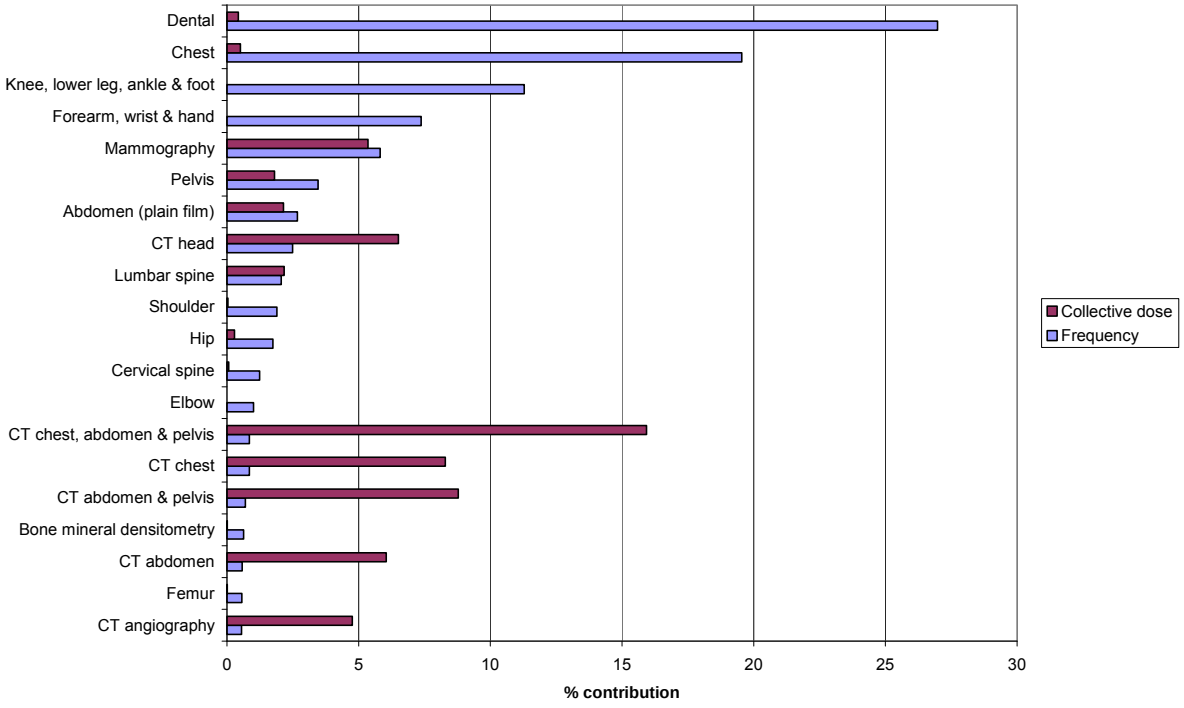

FIGURE 2 Contribution to UK collective dose and frequency from the 20 most frequent medical and dental X-ray examinations

3.6 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 231 types of examination studied in this report.

The uncertainty on the frequencies was evaluated by calculating the standard deviation in the percentage frequency of each examination at each Trust. This calculation was performed across all 29 Trusts which provided frequency data. The standard deviation was then converted to a standard error on the mean by dividing by the square root of the sample size, that is, the total number of that type of examination in the survey. For seven common examinations the standard error was less than 0.1%, whereas for two very rare examinations it was as high as 500%. The overwhelming majority of examinations had a standard error of less than 10%.

For the uncertainty on effective dose, a reliability scale was devised for the previous detailed estimate of collective dose (Hart and Wall, 2002) and the same scheme has been used for this report. This scale gives an approximate indication of the levels of uncertainty involved in the estimates of the typical effective dose 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 16. For example, examinations fall into reliability level A when dose data were obtained from at least 100 UK hospitals and appropriate effective dose conversion coefficients were available. 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. Doses for level E have simply been estimated by comparing with another examination which is thought to be similar in terms of its complexity and the area of anatomy that is under investigation.

TABLE 16 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 PCXMC	±10%
B	>20 UK hospitals Conversion factors available directly from PCXMC	±25%
C	1–19 UK hospitals Conversion factors can be confidently derived from PCXMC	±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

All of the 231 examination types were allocated to a reliability level, as shown in the Appendix. X-ray examinations of the lumbar spine, pelvis, chest, and abdomen along with barium enemas and mammography screening are all in level A because their typical effective doses were based on data from more than 100 UK hospitals. Some of

the more common CT examinations (CT head, CT chest and CT chest hi-resolution) are also in level A.

Approximate ranges of uncertainty (shown in the last column of Table 16) have been attributed to each reliability level based on the dose distributions observed in the National Patient Dose Database. 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 16) of about twice the average random uncertainty on the dose measurements. 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 16. The uncertainty on the collective dose is generally dominated by the uncertainty on the typical effective dose, rather than the uncertainty on the frequency.

Table 17 shows that 69% of the total collective dose estimated for the UK is due to examinations with reliability ratings A and B. Thus a substantial part of the collective dose is known to a reasonable accuracy.

TABLE 17 Uncertainty and collective dose for each reliability rating

Reliability rating	Uncertainty in effective dose (relative)	Collective dose (man Sv)	Percentage collective dose (%)
A	± 10%	6,760	28
B	± 25%	10,232	41
C	± 50%	1,513	6
D	Factor of 2	4,370	18
E	Factor of 3	1,818	7
Total		24,693	100

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 (Taylor & Kuyatt, 1994):

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

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 (Taylor & Kuyatt, 1994):

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

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, and so on.

This resulted in a calculated uncertainty on the total collective dose of about ±3,000 man Sv, i.e. about ±12% of the total collective dose of 24,700 man Sv. The uncertainty on the corresponding per caput dose (0.405 mSv) will also be ±12% (i.e. ±0.049 mSv).

4 DISCUSSION

4.1 Trends in frequency and collective dose in the UK

We have estimated the per caput collective dose from medical X-rays to be 405 ±49 μSv. There has therefore been a probable rise from the estimate of 330 ±30 μSv which we estimated for 1997/98. This rise has been mainly due to a large growth in the use of CT. The numbers of CT examinations have increased by a factor of nearly 2.5 over the last ten years and the collective dose from CT has more than doubled. CT has almost entirely replaced conventional radiographs of the skull, leading to a doubling of the number of CT head examinations. There has been an increase in the numbers for most types of CT examination, including CT of the extremities which have increased by a factor of four. The only examinations which have noticeably decreased in number are CT abdomen and CT pelvis, but this is because the prevalent approach now is to take CT images of more or less the whole trunk, with CT chest & abdomen & pelvis, CT abdomen & pelvis, and CT chest & abdomen all being very common. CT chest & abdomen & pelvis is now the second most common CT examination after CT head, and gives the largest contribution to the UK collective dose of any single examination. The rise in the collective dose from medical X-rays over the last ten years can be almost entirely attributed to the rise in use of these three CT examinations of the trunk.

There has also been a massive increase in the use of CT angiography, from about 5,000 examinations in 1997/98 to more than 250,000 in 2008. CT pulmonary angiography has been the most frequent of these examinations, with nearly 160,000 examinations in 2008. CT pulmonary angiography probably gives a lower effective dose than conventional pulmonary angiography, so this appears to be a beneficial change in terms of dose. However, CT coronary angiography probably gives a higher dose than conventional coronary angiography, but CT has made only slight inroads into this examination so this will only slightly increase the total collective dose. Overall, the changes in CT angiography have probably not had a significant effect on the total collective dose,

Turning to non-CT examinations, bone mineral densitometry has increased in frequency by about a factor of 10. The use of fan beam and cone beam systems has also increased the effective dose for this examination. As a result its collective dose has

increased by a factor of 50. However, it is still an insignificant contributor to the total collective dose.

The number of mammography examinations (both symptomatic and screening) has increased from 1.7 million in 1997/98 to 2.7 million in 2008. The main reason for this increase has been the widening of the age range invited for screening to encompass 50 to 70 year olds. There has also been a doubling of the number of symptomatic examinations. To evaluate the change in the collective dose from all mammography over the last ten years, we must start with a collective dose for 1997/98 calculated without doubling the tissue weighting factor. This amounts to 233 man Sv for all mammography. So the collective dose has more than doubled to reach 550 man Sv in 2008 using ICRP 60 tissue weighting factors. If ICRP 103 tissue weighting factors are used, the value becomes 1300 man Sv. Mammography is therefore a significant contributor to collective dose.

Barium meals, IVUs and radiographs of the skull have continued to decrease in frequency, as was found in the previous collective dose estimate (Hart and Wall, 2002). Barium meals have mostly been replaced by endoscopy. IVUs have halved in number and are commonly substituted by CT (and also ultrasound). Barium enemas have diminished in number by 130,000 but the drop is only partly explained by the take-up of CT virtual colonoscopy (40,000 procedures per year). Probably, conventional colonoscopy covers the difference of 90,000 examinations. Overall, the effective doses from conventional radiology have probably gone down by about 30 to 40% during the period 1998 to 2008, if the trend was similar to that during 1995 to 2005 (Hart et al, 2007; Hart et al, 2002). This explains the reduction in collective dose from conventional radiology shown in Table 15, despite the 5% increase in the number of examinations.

Table 18 compares estimates over the last 30 years for the frequency of X-ray examinations and the resulting per caput dose in Great Britain or the UK. It can be seen that there has been a steady rise in the frequency of medical X-ray examinations and in the per caput dose (along with a slower rise in the population). The frequency of dental X-ray examinations appears to have declined over the last ten years due to our assumption of a constant total number of such examinations, together with a slight increase in the population. Table 18 also compares the UK data with UNSCEAR (2010) data for the world and for Health Care Level 1 (HCL1) countries (defined as countries with at least one physician for every 1000 people). The UK data for 2008 is low in comparison with that for HCL1 and is roughly similar to that for the world as a whole.

TABLE 18 Trends in UK population exposure from medical and dental X-ray examinations

	GB	GB	UK	UK	UK	UK	UNSCEAR	
	1977	1983	1991	1997/98	2001	2008	HCL1	World
Data source	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(7)
Population (millions)	54	56	57	59		61		
Frequency of medical examinations (per 1000 population)	440	488		492		559	1332	488
Frequency of dental examinations (per 1000 population)	106	156		212		193	275	74
Per caput dose from medical & dental X-rays (μSv)		290	350	330	380	400	1920	620

(1) Kendall et al, 1980

(2) Shrimpton and Wall, 1986

(3) Hughes and O'Riordan, 1993

(4) Tanner et al, 2000; & Hart and Wall, 2002

(5) Hart and Wall, 2004

(6) Present study

(7) UNSCEAR, 2010 (review of data from 1997-2070 for Health Care Level 1 countries and the whole world)

4.2 Comparison with other countries

A recent project to compare examination frequencies and effective doses for 2008 across Europe gives an ideal opportunity to compare the UK situation with that in other countries (Aroua et al, 2010). The project looked at twenty common examinations which had previously been found to be the biggest contributors to the collective dose from medical X-rays in Europe, "the Top 20" (Wall et al, 2008). Table 19 compares the examination frequency per 1000 population in 2008 for these top 20 examinations across 13 European countries with the frequency in the UK. (The UK frequencies have been updated from those appearing in the IRPA congress paper (Aroua et al, 2010)). For 19 of these examinations, the UK frequency is less than the European average. Only barium enemas are more frequent in the UK than on average in Europe. For 6 examinations, the UK has the lowest frequency and in no case does it have the highest frequency. It is therefore clear that the UK has a generally low examination frequency in comparison with Europe. Table 19 also compares the UK situation with 16 examinations for which frequency data are available for UNSCEAR Health Care Level 1 countries (UNSCEAR, 2010). For thirteen of these examinations, the UK has a lower frequency than HCL1 countries. Only for coronary angioplasty, cardiac angiography, and mammography is the frequency higher in the UK.

TABLE 19 International comparison of annual examination frequency per 1000 population

Examination*	UK	13 European countries**			UNSCEAR
		Average	Minimum	Maximum	HCL1
Chest/ Thorax	146.7	182.7	104.7	428.1	168
Cervical spine	9.3	16.3	6.5	45.3	32
Thoracic spine	4.4	10.5	4.4	20.6	16
Lumbar spine (inc.LSJ)	14.9	33.8	14.9	59.5	31
Mammography	43.7	61.3	21.7	85.0	43
Abdomen	20.1	22.3	0.7	56.0	45
Pelvis & hip	39.0	53.7	38.2	89.9	40
Barium meal	0.3	2.0	0.0	7.1	
Barium enema	3.8	2.4	0.2	12.5	9.3
Barium follow-through	0.7	0.8	0.1	1.8	
IVU	1.4	2.4	0.1	11.4	8.5
Cardiac angiography	3.3	5.2	1.7	15.0	1.5
CT head	18.7	32.6	18.7	58.0	40
CT neck	0.8	6.9	0.8	34.4	
CT chest	4.8	18.8	4.8	32.6	24
CT spine	1.5	9.0	0.9	33.7	11
CT abdomen	4.3	23.9	3.6	44.8	30
CT pelvis	1.5	4.8	0.6	24.5	19
CT trunk	14.0	19.1	0.5	106.0	
Coronary angioplasty	1.3	2.3	1.3	5.8	0.9

* The “European Top 20” examinations, as defined in Wall et al (2008)

** The 13 countries are Belgium, Denmark, Estonia, Finland, France, Germany, Iceland, Lithuania, Netherlands, Norway, Sweden, Switzerland, UK.

For the same set of “Top 20” examinations, Table 20 shows mean effective doses in 2008 for Europe and the UK, all of them based on ICRP 60. (The UK doses have been updated from those appearing in the IRPA congress paper (Aroua et al, 2010)). The doses estimated for the UK are less than the European average for 17 examinations. For four of these examinations, the UK exhibits the lowest dose. Only mammography, CT neck and CT chest doses are higher than the European average, but the 3 mSv dose assumed for CT neck was actually Australian data rather than from the UK. In no case does the UK have the highest effective dose. In general, UK doses are low compared with Europe. Table 20 also compares the UK situation with 16 examinations for which dose data are available from UNSCEAR Health Care Level 1 countries (UNSCEAR, 2010). For fifteen of these examinations, the UK has a lower dose than HCL1 countries. Only CT spine has a higher dose for the UK than for HCL1, but this assumed UK dose was mainly based on Australian data.

TABLE 20 International comparison of mean effective doses*

Examination**	UK	12 European countries***			UNSCEAR
		Average	Minimum	Maximum	HCL1
Chest/ Thorax	0.014	0.09	0.014	0.29	0.1
Cervical spine	0.03	0.23	0.02	1.1	0.2
Thoracic spine	0.37	0.81	0.3	3.5	0.8
Lumbar spine (inc.LSJ)	0.7	1.32	0.4	4.1	2.2
Mammography	0.21	0.20	0.03	0.35	0.4
Abdomen	0.47	1.19	0.4	2.93	0.8
Pelvis & hip	0.45	0.70	0.25	2	1.1
Barium meal	2	6.38	2	18.5	
Barium enema	3	9.83	2.60	25.73	7.4
Barium follow-through	1.5	9.08	0.63	42.3	
IVU	2.3	2.91	2.1	4.25	2.6
Cardiac angiography	3.9	7.15	1.20	14.4	11.2
CT head	1.6	1.95	1.2	3.05	2.4
CT neck	3	2.70	1.1	5	
CT chest	5.8	5.35	3.5	7.37	7.8
CT spine	6	7.04	3.1	11.81	5.0
CT abdomen	5.1	10.28	5.1	17.9	12.4
CT pelvis	6	7.65	0.8	14.48	9.4
CT trunk	8	15.80	8	33.4	
Coronary angioplasty	7.8	15.04	2.84	23	11.9

* Based on ICRP Publication 60 definition (ICRP, 1991)

** The “European Top 20” examinations, as defined in Wall et al (2008)

*** The 12 countries are Belgium, Denmark, Finland, France, Germany, Iceland, Lithuania, Netherlands, Norway, Sweden, Switzerland, UK.

The European evaluation of collective dose for the “Top 20 “ examinations (Aroua et al, 2010) is not directly comparable with the collective dose estimated in our survey since the latter is for all 231 examinations. However, it is interesting to compare the collective doses estimated just for the “Top 20” in 2008. Table 21 shows the annual collective dose per caput from the “Top 20” for 12 European countries. Clearly the UK has a relatively low collective dose for the “Top 20” compared with these other countries. It is also apparent that, in the UK, the “Top 20” examinations account for about 75% of the total collective dose from all medical and dental x-ray examinations.

TABLE 21 Collective dose per caput in 2008 for the "Top 20" examinations in Europe (Aroua et al, 2010)

Country	Annual collective dose per caput (mSv)
Germany	1.52
Belgium	1.39
Switzerland	1.37
Iceland	1.28
France	1.11
Norway	0.94
Sweden	0.59
Netherlands	0.48
Lithuania	0.47
Denmark	0.46
Finland	0.35
UK	0.30

The UK collective dose per caput from all medical and dental X-ray examinations, as stated in section 3.5, stands at 0.4 mSv. This number can be compared with corresponding values of 2.2 mSv assessed for medical and dental X-rays in the USA in 2006 (NCRP, 2009) and the similar figure of 1.9 mSv quoted by UNSCEAR (2010) as the average for people living in Healthcare Level 1 (HCL1) countries. The UK collective dose per caput is clearly very low for a Healthcare Level 1 country.

Table 22 compares the percentage contribution to frequency and percentage contribution to collective dose for examinations in the UK with those in UNSCEAR Health Care Level 1 countries, when there is directly comparable data. Mammography and dental examinations are relatively more frequent in the UK, while chest, skull and examinations of the spine are relatively less frequent in the UK. CT also appears to be relatively less frequent in the UK but this is misleading and occurs because the UNSCEAR review does not include the examinations CT chest & abdomen & pelvis, CT abdomen & pelvis, CT chest & abdomen, and CT angiography, all of which have become common in the UK. Non-CT chest radiography makes a much bigger relative contribution to collective dose in UNSCEAR HCL1 because photofluorography is apparently much more common than in the UK.

The UK annual per caput dose from CT is 0.27 mSv. This number can be compared with corresponding levels of 1.5 mSv from CT in the USA in 2006 (NCRP, 2009) and 0.74 mSv from CT in Canada in 2006 (Chen and Moir, 2010). The UK per caput dose from CT is low compared to North America.

The present estimate for the UK annual per caput dose from all medical and dental X-ray examinations (0.4 mSv) is more than ten times larger than the corresponding per caput dose (0.03 mSv) previously assessed for diagnostic nuclear medicine procedures in the UK (Hart and Wall, 2005).

TABLE 22 Comparison of data from UK and UNSCEAR Health Care Level 1 countries concerning the relative importance of selected examinations to total frequency and collective dose for medical and dental X-ray examinations

	United Kingdom		UNSCEAR HCL1	
	Relative frequency	Relative collective dose	Relative frequency	Relative collective dose
Examination	%	%	%	%
Abdomen (plain film)	2.7	2.1	2.8	1.9
Ba enema	0.5	2.1	0.6	3.6
Cervical spine	1.2	0.1	3.2	0.4
Chest	19.6	0.5	33.3	15.0
Coronary angiography	0.4	3.2	0.1	0.9
CT abdomen	0.6	6.0	1.8	19.0
CT chest	0.8	8.3	1.5	9.7
CT head	2.5	6.5	2.5	5.0
CT pelvis	0.2	2.3	1.2	9.3
CT spine	0.2	1.5	0.7	2.9
Dental	26.0	0.4	17.0	0.3
Lumbar spine	2.1	2.2	3.3	3.2
Mammography	5.8	5.4	2.6	0.7
Other angiography	0.2	1.4	0.2	2.1
Pelvis	3.5	1.8	2.5	2.4
PTCA	0.2	2.8	0.1	0.6
Skull	0.1	0.01	2.7	0.2
Thoracic spine	0.5	0.4	1.6	0.6
Total	67.1	47.0	77.7	77.7

5 CONCLUSIONS

The total number of medical and dental X-ray examinations carried out in the UK in 2008, both inside and outside the NHS, is estimated to be 46 million. This is an increase of 10% compared to the 41.5 million examinations carried out in the financial year 1997/98. Within that total, there has been an even bigger growth in computed tomography (CT). Whereas there were 1.4 million CT examinations in 1997/98, there were 3.4 million CT examinations in 2008 (140% increase). This increase in the frequency of CT has led to an increase in the collective dose from medical and dental X-ray examinations.

The annual per caput dose from medical and dental X-ray procedures in the UK has been estimated by combining the results from a survey of the frequency of 231 types of examination with data from the National Patient Dose Database for 2001-2005 on radiation doses from such examinations. The per caput dose from all X-ray imaging performed in hospitals and clinics in the NHS and the independent sector is estimated to be 405 μSv per year. This is an increase on the estimate for the financial year 1997/98

of 330 μSv. However it still appears to be relatively low in comparison with other European countries, North America and UNSCEAR Health Care level 1 countries. This is due to both a lower frequency of X-ray examinations and to lower effective doses per examination in the UK.

The use of CT is now responsible for 68% of the total collective dose from X-ray examinations, compared with 40% in 1997/98. There has been a diminution of the relative collective dose from conventional radiology, which has fallen from 44% in 1997/98 to 19% in 2008, although these examinations account for 90% of the total number. (They accounted for 95% of the total number in 1997/98.)

Figure 3 shows the change in the relative contributions from CT, angiography, interventional procedures, and conventional radiology to the UK collective dose from all medical X-ray examinations (based on ICRP 103).

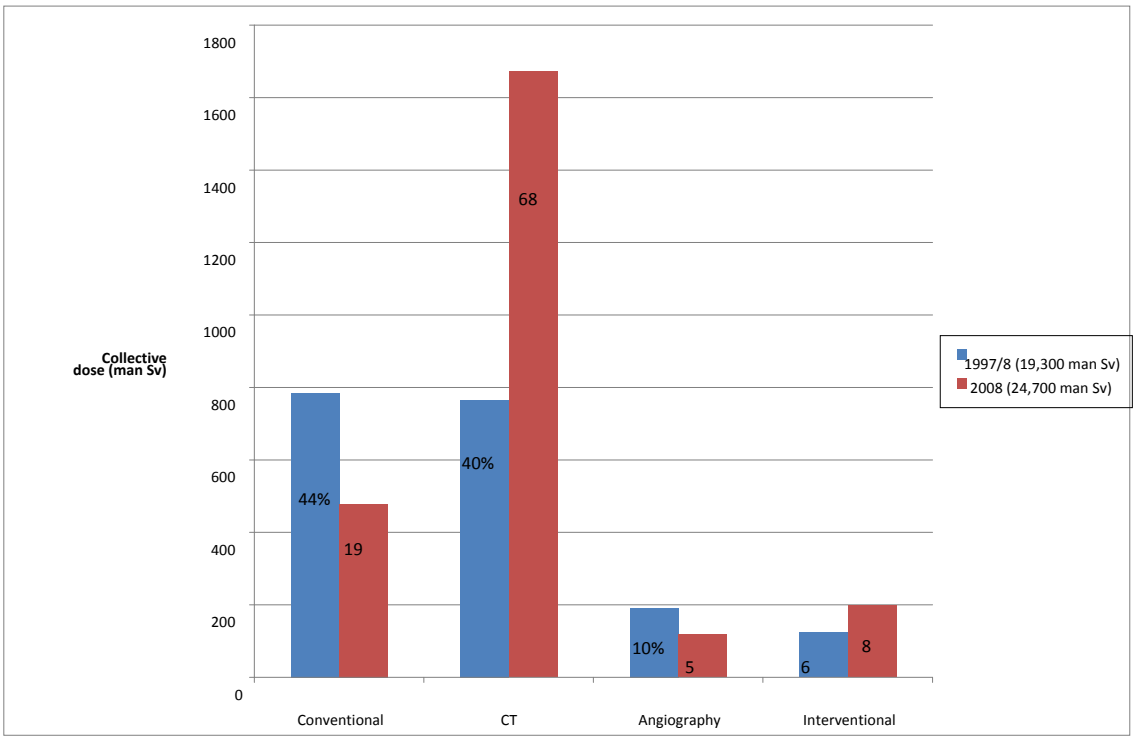

FIGURE 3 Comparison by broad type of contributions to UK collective dose from medical and dental X-ray examinations

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APPENDIX A

Data used to calculate collective dose in the UK

Category / Examination	No. of exams in UK	E60 mSv	E103 mSv	Sources	Reliability for E	Collective dose (E60 man Sv)	Collective dose (E103 man Sv)	% collective dose (E103)
Skull & facial bones								
Nasal bones	1,656	0.03	0.04	cf facial bones	E	0.05	0.07	0.000
Facial bones	157,316	0.03	0.04	PA + LAT cf skull	E	4.72	6.42	0.026
Mastoids	634	0.05	0.07	cf skull	E	0.03	0.04	0.000
Skull	53,506	0.05	0.07		B	2.68	3.64	0.015
		0.043		NPDD (PA + LAT + AP)				
		0.055		NPDD (PA + LAT + AP)				
Cephalogram	57,966	0.003	0.004	1	D	0.17	0.24	0.001
Mandible	55,956	0.007	0.010		C	0.39	0.53	0.002
		0.012		NPDD				
		0.003		NPDD				
Temporo-mandibular joint	2,078	0.005	0.007	cf temporo-mandibular joints	E	0.01	0.01	0.000
Temporo-mandibular joints	4,553	0.01	0.014	cf mandible	E	0.05	0.06	0.000
Paranasal sinuses	18,905	0.011	0.016	NPDD	D	0.22	0.30	0.001
Head - soft tissue								
Dacryocystography	1,825	0.08	0.11	NPDD	C	0.15	0.21	0.001
Sialography	11,632	0.045	0.06	NPDD	C	0.52	0.71	0.003
Orbits	38,098	0.036	0.05	NPDD AP or LAT	D	1.37	1.87	0.008
Teeth - dental hospital								
Teeth, up to 2 films	124,177	0.003	0.005	2, 3	D	0.37	0.62	0.003
Teeth >2 films	3,844	0.009	0.015		D	0.03	0.06	0.000
Teeth, panoramic	551,641	0.009	0.019	2, 3	D	4.96	10.48	0.042
Dental practice								
Intraoral exams	9127000	0.003	0.005	2, 3	D	27.38	45.64	0.185
Panoramic radiographs	2701350	0.009	0.019	2, 3	D	24.31	51.33	0.208
Cerebral angiography								
Carotid angiography	710	6.2	8.45	NPDD	C	4.41	6.00	0.024

Cerebral angiography	7,797	1.75	2.38	NPDD	C	13.62	18.53	0.075
Wada Test	34	0.84	1.14	NPDD	C	0.03	0.04	0.000
Neck - soft tissue								
Soft tissues of the neck	23,061	0.008	0.008	NPDD	D	0.18	0.18	0.001
Myelography								
Myelo-, Disco-, Radiculography	5,601	2.61	2.38	NPDD disco, myelo,	C	14.62	13.30	0.054
Cervical spine	573,181	0.030	0.03		C	17.20	17.20	0.070
		0.026		NPDD(AP+LAT)				
		0.033		NPDD(AP+LAT)				
Thoracic spine	236,464	0.37	0.38		B	87.49	89.86	0.364
		0.45		NPDD(AP+LAT)				
		0.29		NPDD(AP+LAT)				
Thoraco-lumbar spine	35,040	1.1	1.1	Tspine + Lspine	E	38.54	38.54	0.156
Lumbar spine	868,268	0.7	0.6		A	607.79	520.96	2.110
		0.8		NPDD(AP+LAT)				
		0.6		NPDD(AP+LAT)				
Lumbo-sacral joint	44,298	0.21	0.17		B	9.30	7.54	0.031
LSJ		0.24		NPDD				
		0.19		NPDD				
Sacro-iliac joints	18,728	0.21	0.17	as LSJ	E	3.93	3.18	0.013
Sacrum and coccyx	17,849	0.21	0.17	as LSJ	E	3.75	3.03	0.012
Whole spine/scoliosis	41,071	0.12	0.12	NPDD spine	C	5.13	4.93	0.020
		0.10		NPDD spine AP				
Shoulder girdle								
Shoulder	843,719	0.012	0.011	AP + Axial	C	10.12	9.28	0.038
		0.010		NPDD exam				
Shoulders	29,169	0.024	0.02	twice shoulder	C	0.70	0.64	0.003
Acromioclavicular joint	8,659	0.012	0.01	shoulder	E	0.10	0.10	0.000
Acromioclavicular joints	4,646	0.024	0.02	twice shoulder	E	0.11	0.10	0.000
Clavicle/collar bone	109,960	0.012	0.01	shoulder	E	1.32	1.21	0.005
Clavicles	693	0.024	0.02	twice shoulder	E	0.02	0.02	0.000
Scapula	11,936	0.012	0.01	shoulder	E	0.14	0.13	0.001
Scapulas	76	0.024	0.02	twice shoulder	E	0.00	0.00	0.000
Sternoclavicular joints	5,685	0.024	0.02	twice shoulder	E	0.14	0.13	0.001

Sternum	20,147	0.024	0.02	twice shoulder	E	0.48	0.44	0.002
Upper arm (humerus)	223,290	0.0009	0.0009	2 X elbow	E	0.20	0.20	0.001
Upper arm (both)	3,142	0.0018	0.0018		E	0.01	0.01	0.000
Elbow	465,900	0.0005	0.0005	NPDD	C	0.21	0.23	0.001
Elbow (both)	5,879	0.0009	0.0009		C	0.01	0.01	0.000
Forearm, wrist & hand								
Fingers	505,907	0.0001	0.0001	NPDD	C	0.05	0.05	0.000
		0.00001		NPDD				
Hand	795,053	0.0002	0.0002	NPDD	C	0.16	0.16	0.001
Hand both	160,932	0.0004	0.0004		C	0.06	0.06	0.000
Hand & wrist (bone age)	14,775	0.0002	0.0002	cf hand	E	0.00	0.00	0.000
Radius & ulna/forearm	258,111	0.0004	0.0004	NPDD	C	0.09	0.10	0.000
Radius & ulna/forearm (both)	1,512	0.0007	0.0007		C	0.00	0.00	0.000
Thumb	272,598	0.0001	0.0001	NPDD Thumb, Finger/thumb	C	0.03	0.03	0.000
		0.0001		NPDD (AP or LAT)				
Thumb (both)	6,859	0.0002	0.0002		C	0.00	0.00	0.000
Wrist/scaphoid	1,344,811	0.0003	0.0003	NPDD	C	0.34	0.40	0.002
Wrist (both)	36,239	0.0006	0.0006		C	0.02	0.02	0.000
Orthopaedic pinning								
Upper limb	30,808	0.0003	0.0003	NPDD	C	0.01	0.01	0.000
Upper limb (both)	161	0.0006	0.0006		C	0.00	0.00	0.000
Lower limb	40,159	0.0035	0.0035	NPDD	C	0.14	0.14	0.001
Lower limb (both)	76	0.0070	0.0070		C	0.00	0.00	0.000
Pelvis	1,591,855	0.45	0.28		A	716.33	445.72	1.805
		0.49		NPDD (AP)				
		0.409		NPDD (AP)				
		0.47		NPDD (exam)				
Hip	804,599	0.15	0.087		C	120.69	70.00	0.283
		0.22		NPDD (AP)				
		0.09		NPDD (AP)				
Orthopaedic pinning (hip)	16,439	0.20	0.12	NPDD	C	3.34	1.94	0.008
Femur	259,327	0.022	0.012	NPDD (AP+LAT)	C	5.71	3.11	0.013

Femur (both)	6,640	0.04	0.02		C	0.29	0.16	0.001
Leg length	28,257	0.02	0.02	NPDD	D	0.59	0.57	0.002
Knee, lower leg, ankle & foot								
Ankle	1,145,874	0.0005	0.0005	NPDD (exam)	C	0.52	0.57	0.002
		0.0003		NPDD (unknown proj)				
Ankle (both)	32,396	0.0009	0.0009		C	0.03	0.03	0.000
Foot	1,208,571	0.0002	0.0002	NPDD	C	0.24	0.24	0.001
Foot (both)	164,927	0.0004	0.0004		C	0.07	0.07	0.000
Knee	1,793,073	0.0004	0.0002	NPDD (AP+LAT)	C	0.67	0.36	0.001
		0.0006		NPDD (exam)				
		0.0003		NPDD (AP+LAT)				
Knee (both)	267,952	0.0008	0.0004		C	0.21	0.11	0.000
Calcaneum/heel	76,111	0.0004	0.0004	NPDD	D	0.03	0.03	0.000
Calcaneum (both)	4,883	0.0008	0.0008		D	0.00	0.00	0.000
Tibia & fibula	344,477	0.0008	0.0008	NPDD	C	0.28	0.28	0.001
Tibia & fibula (both)	5,009	0.0016	0.0016		C	0.01	0.01	0.000
Toes	155,348	0.0002	0.0002	NPDD	C	0.02	0.02	0.000
Arthrography	21,490	0.19	0.10	NPDD	C	4.03	2.18	0.009
Arthrography Shoulder	11,446	0.08	0.08	NPDD	C	0.95	0.88	0.004
Skeletal survey	23,501	0.05	0.05	NPDD	D	1.06	1.18	0.005
Chest								
Chest/ribs	9,005,834	0.014	0.014	NPDD (PA)	A	125.63	126.08	0.511
		0.015		NPDD (PA)				
		0.031		NPDD (LAT)				
		0.025		NPDD (LAT)				
		0.017		NPDD exam				
Thoracic inlet	2,729	0.045	0.045	PA + LAT	E	0.12	0.12	0.000
Bronchography	414	0.028	0.028	2 X chest	E	0.01	0.01	0.000
Chest/abdomen	66,895	0.47	0.45	as abdomen	E	31.44	30.18	0.122
Mammography								
Mammography symptomatic	652,301	0.21	0.5		E	136.98	326.15	1.321
Mammography screening	1,937,484	0.21	0.5	4, 5	A	406.87	968.74	3.923
Mammography recall for assessment	89,849	0.13	0.3		E	11.68	27.85	0.113

Angiography (general/abdominal)	6,412	9.4	8.51	NPDD	C	59.99	54.59	0.221
Linogram	2,855	0.2	0.2	NPDD	C	0.59	0.57	0.002
Pulmonary angiography								
Pulmonary arteriography	1,200	8.2	8.2	NPDD	C	9.80	9.80	0.040
Pulmonary artery pressures	84	8	8.0	Pulmon. arteriography	E	0.67	0.67	0.003
Sup. venacavography	304	1.1	1.1	NPDD	D	0.34	0.34	0.001
Venacavogram	8	1.3	1.3	Mean SVC, IVC	D	0.01	0.01	0.000
Abdominal angiography								
Inf. venacavography	287	1.5	1.33	NPDD	D	0.42	0.38	0.002
Mesenteric angiography	1,140	47.5	43.24	NPDD	C	54.17	49.30	0.200
Renal arteriography	2,652	17.4	15.82	NPDD	C	46.10	41.95	0.170
Aortography								
Aortography	1,715	5.1	5.1	NPDD	C	8.78	8.78	0.036
Thoracic aortography/arch angiogram	5,398	3.6	3.6	NPDD	C	19.40	19.40	0.079
Abdominal aortography	946	48.5	48.5	NPDD	C	45.89	45.89	0.186
		14		6 USA				
Angiocardiography								
Coronary angiography	202,408	3.9	3.9	NPDD	B	790.69	789.39	3.197
		5.3		7 Europe				
Coronary graft angiography	2,821	6.4	6.4	NPDD	C	18.14	18.05	0.073
Electrophysiology	4,857	3.3	3.3	NPDD	C	15.95	16.03	0.065
Right heart study	6,251	4.3	4.3	NPDD	C	27.17	26.88	0.109
Peripheral angiography								
Femoral angiogram lower limbs	31,855	2.8	2.3	NPDD	B	89.60	73.27	0.297
Angiogram upper limbs	735	0.46	0.46	NPDD	D	0.34	0.34	0.001
Venography of a limb	12,806	0.56	0.56	NPDD	C	7.14	7.17	0.029
Abdomen (plain film)	1,232,410	0.47	0.43	AP	A	579.23	529.94	2.146
		0.51		NPDD (AP)				
		0.43		NPDD (AP)				
Foreign body demonstration	29676	0.5	0.46	cf abdomen	E	14.84	13.50	0.055
Oesophagus								
Ba swallow	97,846	1.40	1.5	NPDD	B	136.69	146.77	0.594
Ba video swallow	13,600	0.48	0.52	NPDD +videofluoroscopy	C	6.55	7.01	0.028

Stomach & duodenum								
Ba meal	20,798	1.98	1.98	NPDD	B	41.10	41.18	0.167
Ba meal & swallow	17,368	1.98	1.98	NPDD	B	34.32	34.39	0.139
Small intestine								
Ba follow-through/small bowel meal	44,577	1.50	1.3	NPDD	B	66.87	57.95	0.235
Small bowel enema or enteroclysis	5,026	4.07	3.54	NPDD	B	20.43	17.77	0.072
Colon								
Ba enema	233,140	3.03	2.2	NPDD	A	705.48	512.91	2.077
Proctogram	7,696	2.09	1.53	NPDD	C	16.09	11.75	0.048
Colonic transit study	2,475	1.88	1.37	4 X abdomen	E	4.65	3.40	0.014
Other abdominal investigations								
Fistulogram	8,329	2.9	2.65	NPDD	C	24.24	22.06	0.089
Herniography	4,486	3.5	3.21	NPDD	C	15.81	14.39	0.058
Loopogram gastrointestinal tract	380	1.08	0.98	NPDD	C	0.41	0.37	0.002
Loopogram urinary tract	1,352	1.70	1.55	cf retrograde pyelogram	E	2.30	2.09	0.008
Ileoanal pouchogram	414	2.3	2.05	NPDD	C	0.93	0.85	0.003
Sinography	1,554	1.3	1.15	NPDD	C	1.97	1.79	0.007
Biliary system								
Cholangiography, operative	5,322	5.7	5.17	NPDD Cholangiogram	D	30.24	27.52	0.111
Cholangiography, intravenous	93	5.7	5.19	Cholangiog., operative	E	0.53	0.48	0.002
ERCP	61,911	2.7	2.46	NPDD	B	167.45	152.38	0.617
Cholangiography, percutaneous (PTC)	6,209	5.0	4.58	NPDD	C	31.23	28.42	0.115
T-tube Cholangiography, post-op	4,899	1.2	1.10	NPDD	C	5.94	5.40	0.022
Kidneys and ureters								
Antegrade pyelography (percutaneous)	186	1.70	1.55	cf retrograde pyelogram	E	0.32	0.29	0.001
Nephrostogram, post-op	7,231	1.6	1.50	NPDD	C	11.93	10.85	0.044
Nephrostogram both	1,799	3.2	2.91		C	5.76	5.24	0.021
Retrograde pyelogram	7,552	1.7	1.58	NPDD	C	13.08	11.91	0.048
Retrograde pyelogram both	490	3.4	3.09		C	1.67	1.52	0.006
IVU	84,086	2.3	2.1	NPDD	B	193.13	176.58	0.715
Bladder and urethra								
Urodynamics	6,412	0.6	0.58	NPDD BP,U	C	4.08	3.71	0.015
Cystography	6,412	0.6	0.53	NPDD	C	3.75	3.41	0.014

Excretion urography/MCU	10,483	2.0	1.86	NPDD	C	21.45	19.52	0.079
Urethrography	2,627	1.4	1.30	NPDD	C	3.76	3.42	0.014
Gynaecology								
Hysterosalpingography	21,938	0.5	0.42	NPDD	B	10.14	9.22	0.037
Bone mineral densitometry	291,664	0.01	0.01	8, 9	D	2.92	2.92	0.012
Fluoroscopy	48,132	1.6	1.6		E	77.01	77.01	0.312
Computed tomography								
CT head	1,148,670	1.6	1.4	10	A	1837.87	1608.14	6.512
CT neck	49,029	3	3	11 Australia	D	147.09	147.09	0.596
CT abdomen	266,719	5.1	5.6	10	B	1360.27	1493.63	6.049
CT chest	292,559	5.8	6.6	10	A	1696.84	1930.89	7.819
CT chest (hi resolution)	97,813	1.2	1.2	10	A	117.38	117.38	0.475
CT enteroclysis	7,425	13	13	12 Switzerland	D	96.53	96.53	0.391
		16		13 USA				
CT pelvis	92,710	6	6	14 USA	D	556.26	556.26	2.253
CT abdomen & pelvis	323,629	6.8	6.7	10	B	2200.68	2168.31	8.781
CT chest & abdomen	145,287	7	7	btn chest and abdo+pelvis	E	1017.01	1017.01	4.118
CT chest, abdomen & pelvis	393,387	9.2	10	10	B	3619.16	3933.87	15.931
CT liver	13,203	7	7	10, 11, 14	D	92.42	92.42	0.374
CT liver three phase	4,781	14	14	11, 14	D	66.93	66.93	0.271
CT extremity	72,783	0.6	0.6	15 Switzerland	D	43.67	43.67	0.177
CT cervical spine	51,360	1.9	1.9	11 Australia	D	97.58	97.58	0.395
CT thoracic spine	9,402	4.4	4.4	Mean cerv/lumbar	E	41.37	41.37	0.168
CT lumbar spine	29,101	6.9	6.9	11 Australia	D	200.80	200.80	0.813
CT whole spine	4,156	10	10	as chest/abdo/pelvis	E	41.56	41.56	0.168
CT interventional	24,388	10	10		D	243.88	243.88	0.988
		20		16 Belgium				
		0.1		17 USA				
		15 to 35		18 Greece				
		2 to 4		19 Germany				
		0.15		20 Ireland				

CT bone mineral densitometry	1,774	0.04	0.04	14 USA	D	0.07	0.07	0.000
		0.03 to 0.06		21 USA				
CT angiography	31,389	5	5	abdomen	E	156.95	156.95	0.636
CT angiography (aortic)	52,053	5.2	5.2	11 Australia	D	270.68	270.68	1.096
CT angiography (pulmonary)	158,279	3.3	3.3	11 Australia	D	522.32	522.32	2.115
		15		14 USA				
		3 to 5		22 USA				
CT angiography (coronary)	14,141	16	16	14 USA	D	226.26	226.26	0.916
		18		23	C			
		12		24 Germany/USA				
		9 to 16		25 USA				
CT calcium scoring	4,000	3	3	14 USA	D	12.00	12.00	0.049
				26 USA				
CT virtual colonoscopy	41,080	10	10	14 USA	D	410.80	410.80	1.664
		6.4 to 8.8		27 Germany				
		15 to 20		28 Germany				
		9.1		29 Europe				
		3 to 6		30 Europe				
CT KUB	54,629	5.5	5.5		D	300.46	300.46	1.217
		4.2		11 Australia				
		7.1 to 9.7		31				
		6.5 to 8.5		32 USA				
		7.7		33 Norway				
		1.4 to 4.4		34 Belgium				
		1.6		35 Belgium				
		1.9 to 11.1		36 Switzerland				
CT urogram	37,042	25	25		D	926.05	926.05	3.750
		16		37 USA				
		25-35		38 USA/UK				
		15		39 USA				
		40		40 USA				
Interventional radiology								

Biopsy								
Pathological specimen	8,253	2.6	2.6	biopsy/liver biopsy	E	21.57	21.46	0.087
Biopsy	6,006	2.6	2.6	NPDD	C	15.34	15.62	0.063
Biopsy of lung	17	0.4	0.4	NPDD	C	0.01	0.01	0.000
Liver biopsy transjugular	1,478	2.7	2.7	NPDD	C	3.95	3.99	0.016
Venous sampling	169	0.56	0.56	cf venography	E	0.09	0.09	0.000
Biliary & urinary systems								
Biliary drainage	3,455	7.5	6.85	NPDD	C	26.00	23.66	0.096
Biliary intervention & stenting	3,860	7.1	6.49	NPDD	B	27.51	25.04	0.101
Cholecystostomy	405	7.5	6.83	biliary drainage	E	3.04	2.76	0.011
Lithotripsy	735	1.6	1.46	41 Greece	D	1.18	1.07	0.004
Nephrostomy	12,680	2.3	2.09	NPDD + N Drainage	B	29.12	26.50	0.107
Nephrostomy both	1,377	4.6	4.19		B	6.33	5.76	0.023
Percutaneous Nephrolithotomy	3,185	1.0	0.91	42 India	D	3.19	2.90	0.012
Ureteric stenting	15,628	5.9	5.41	NPDD	C	92.83	84.48	0.342
Ureteric stenting both	1,368	11.8	10.74		C	16.14	14.69	0.059
Urethral stent	363	3.0	2.73	half ureteric stent	E	1.09	0.99	0.004
Cardiovascular								
Angioplasty	17,106	4.4	4.4	NPDD	C	75.19	75.27	0.305
Angioplasty(femoral)	11,953	3.0	2.71	NPDD	C	35.62	32.41	0.131
Angioplasty(iliac)	7,510	14.3	13.01	NPDD	C	107.39	97.73	0.396
PTCA	88,453	7.8	7.8	NPDD all PTCA	B	685.69	689.93	2.794
		7.3		7 Europe				
stenting		7.6		7 Europe				
Dialysis line	1,656	3.7	3.7	NPDD +tesioline	C	6.20	6.13	0.025
Embolisation	8,135	21.1	21.1	NPDD	C	171.70	171.65	0.695
(Aneurysm)	431	19.8	19.8	NPDD	C	8.52	8.53	0.035
(Cerebral)	1,858	4.4	6.04	NPDD inc GDC	C	8.26	11.23	0.045
(Fibroids/uterine artery)	1,968	8.3	7.57	NPDD	C	16.37	14.89	0.060
(varicocele)	1,461	10.6	6.55	NPDD	C	15.43	9.57	0.039
Hickman line	29,211	0.25	0.25	NPDD	C	7.38	7.30	0.030
Insertion of pacemaker	44,610	1.1	1.1	NPDD	C	48.72	49.07	0.199

		3.1		7 Europe				
RF Card.Cath.Ablation	8,397	6.9	6.9	NPDD EPS+RFA, 2*RFCA	C	57.95	57.94	0.235
Stent graft aorta	2,897	38.2	38.2	NPDD	C	110.74	110.67	0.448
Thrombolysis	1,563	2.0	2	NPDD	C	3.09	3.13	0.013
TIPS stent insertion	726	47.9	43.60	NPDD	C	34.79	31.66	0.128
		70		14 USA				
TIPS shuntogram	237	0.2	0.2	linogram	E	0.05	0.05	0.000
Valvuloplasty (mitral)	405	3.52	3.52	NPDD	D	1.42	1.43	0.006
Vascular stenting	12,029	19.8	19.8	NPDD	B	238.17	238.17	0.965
Insertion of caval filters	2,323	3.6	3.6	NPDD Filter (IVC,SVC,VC)	C	8.26	8.36	0.034
Removal of intravascular foreign body	338	0.3	0.3	as femoral angiogram	E	0.10	0.10	0.000
Gastrointestinal								
Nasogastric tube	7,468	1.2	1.2	NPDD + feeding tube+PEG	C	9.01	8.96	0.036
Gastrostomy	2,805	2.8	2.52	NPDD	C	7.78	7.08	0.029
Lap-band (Gastric band)	3,261	0.5	0.47	NPDD	C	1.68	1.53	0.006
Oesophageal dilation	2,458	1.0	1	NPDD	C	2.56	2.46	0.010
Oesophageal stent	4,384	2.0	2	NPDD	C	8.80	8.77	0.036
Colonic stent	1,411	17.5	10.86	NPDD	C	24.71	15.32	0.062
Enteric stent	971	11.3	7.02	NPDD duoden+pyloric	D	11.00	6.82	0.028
Rectal stent	161	8.6	5.33	NPDD	D	1.38	0.86	0.003
Other interventional								
Drainage	794	1.1	1.1	NPDD	C	0.90	0.87	0.004
Nerve root injection (spine)	59,740	0.85	0.85	NPDD	B	50.54	50.78	0.206
Lumbar Puncture	93	3.3	2.99	NPDD	C	0.31	0.28	0.001
Vertebroplasty	1,521	2.8	2.57	NPDD	C	4.29	3.90	0.016
Fluoroscopy guided injections	55,119	0.46	0.42	NPDD	C	25.35	23.07	0.093
Total	**46,139,350**					**24246.75**	**24694.11**	**100.00**

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