EUROPEAN COMMISSION

RADIATION PROTECTION N° 154

European Guidance on Estimating Population Doses from Medical X-Ray Procedures

ANNEX 1 – DD Report 1

REVIEW OF RECENT NATIONAL SURVEYS OF POPULATION EXPOSURE FROM MEDICAL X-RAYS IN EUROPE

Directorate-General for Energy and Transport
Directorate H — Nuclear Energy
Unit H.4 — Radiation Protection
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Prepared by

Health Protection Agency
Centre for Radiation, Chemical and Environmental Hazards
Radiation Protection Division
Chilton, Didcot, Oxfordshire OX11 0RQ

This report is one of three that have been prepared under a contract to the European Commission for the 'Development of a harmonised methodology for dose data processing regarding radiodiagnostic imaging procedures in medical applications – DOSE DATAMED'.

The participants in the DOSE DATAMED project over the three years of its activities were as follows:

B. Wall, UK (Co-ordinator)
D. Hart, UK
H. Mol, BE
A. Lecluyse, BE
A. Aroua, CH
P. Trueb, CH
J. Griebel, DE
E. Nekolla, DE
P. Gron, DK
H. Waltenburg, DK
H. Beauvais-March, FR
B. Aubert, FR
P. Scanff, FR
P. Pirard, FR
S. Sinno-Tellier, FR
F. Shannoun, LU
M. Brugmans, NL
E. Meeuwsen, NL
P. Stoop, NL
H. Olerud, NO
I. Borretzen, NO
W. Leitz, SE

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1. Introduction

The European Commission, on advice from the Article 31 Group Working Party on Medical Exposures, instigated a study at the end of 2004 to review the current situation in Member States regarding implementation of Article 12 of the Medical Exposure Directive of 1997 [EC, 1997] and to develop appropriate guidance. Article 12, entitled 'Estimates of population doses', requires Member States to ensure that the distribution of individual dose estimates from medical exposure is determined for the population and for relevant reference groups of the population, as may be deemed necessary by the Member State. The Commission was concerned that there were no internationally accepted protocols for evaluating patient exposures from medical x-ray imaging procedures and that reported estimates of population doses varied widely between European countries with similar levels of health care. It was thought that some of this variation might be due to differences in the methodology adopted to assess population doses between Member States and to large inherent uncertainties in these assessments that had not been fully evaluated.

A multinational project (called DOSE DATAMED) involving ten European countries was set up to carry out this study. All project partners and the institutes that they work for have long experience of conducting national surveys of population exposure from medical radiology. The project has built upon this experience to review the existing national arrangements and strategies for carrying out these surveys in each country. It has looked at the different healthcare systems operating in each country to see if they could account for some of the differences observed in the population doses. It has then studied and compared the methods and results of the most recent population dose surveys in each country and evaluated the uncertainties. This report - **DD Report 1** – presents the results and conclusions from this review of recent national surveys of population exposure from medical x-rays in Europe.

Although the main emphasis in this project has been on population exposures from medical x-ray imaging procedures, many of the DOSE DATAMED partners had recently conducted national population dose surveys for diagnostic nuclear medicine procedures as well. Consequently, a supplementary report – **DD Report 1(a)** – '*Review of national surveys of population exposure from nuclear medicine examinations in eight European countries'* has been prepared, which provides a brief review of just the major features of these recent national nuclear medicine surveys.

Recommendations for the development of a harmonised system for assessing patient doses and the level of provision of diagnostic radiology services in Member States, in order to assess population doses in the future, are given in **DD Report 2** – 'Guidance on estimating population doses from medical radiology'. In view of the relatively low contribution of nuclear medicine to population exposure compared to medical x-rays, this guidance concentrates on population dose assessments for the x-ray imaging procedures used in diagnostic and interventional radiology.

2. History of population dose assessments from medical x-rays in Europe

There has been a long history of carrying out periodic reviews of the population exposure from diagnostic radiology going back to the 1950s in five European countries - UK, Switzerland, Germany, Sweden and Norway. In those early days the possible genetic effects of exposure to ionising radiation were of primary concern and the reviews concentrated on estimating the annual genetically significant dose to the population. The considerable resources and effort required to reliably determine the frequency of the different types of x-ray examination and the associated patient doses meant that few countries were able to conduct such complex surveys and those that did could not repeat them very frequently. The five countries mentioned above managed to repeat these initial surveys only after 10-20 years and were joined by the Netherlands in the 1960s and France in the 1980s. From the 1970s onwards the somatic effects of radiation were recognised and following the 1977 and 1990 recommendations of the ICRP, population exposures were generally expressed in terms of the annual collective effective dose.

The table below indicates the timing of the major national surveys of population exposure from diagnostic radiology in the seven European countries. The letter 'G' denotes the earlier surveys that assessed only the annual genetically significant dose to the population and the letter 'S' denotes the later surveys where the somatic effects of radiation on the population were also taken into account, usually by assessment of the collective effective dose. The position of the letter within each decade indicates roughly when the surveys were carried out.

Country	**Decade of surveys**					
	1950s	**1960s**	**1970s**	**1980s**	**1990s**	**2000s**
United Kingdom	G		G	S	S	S
Switzerland	G		G S		S S	S
Germany	G		S	S	S S	S
Sweden	G		S		S	
Norway	G			S	S	S
Netherlands		G	G	GS S S	S	S
France				S S	S	S

Representatives from these 7 European countries were the founder members of the DOSE DATAMED project, which is being funded by the EC to develop harmonised guidance on how to perform population dose assessments from diagnostic radiology. They have subsequently been joined by representatives from Belgium, Denmark and Luxembourg, who have been engaged in similar surveys in recent years. Thus 10 European countries that have considerable experience of estimating population doses from diagnostic radiology are represented in the DOSE DATAMED project. The national arrangements, responsibilities and legal provisions for regularly assessing and reporting population doses from diagnostic radiology in each of the 10 countries represented in the DOSE DATAMED project are discussed below.

3. National arrangements and responsibilities

It was not until 1997 that there were any legal requirements for EC Member States to estimate population doses from medical exposures. Prior to 1997 assessments of population exposure from medical (or any other) radiation sources had been carried out by the national radiation protection organisations or public health bodies in each country that considered such matters to be within their remit. The official bodies that are currently in charge of population dose assessments in the 10 European countries in the DOSE DATAMED project are shown in the Table below.

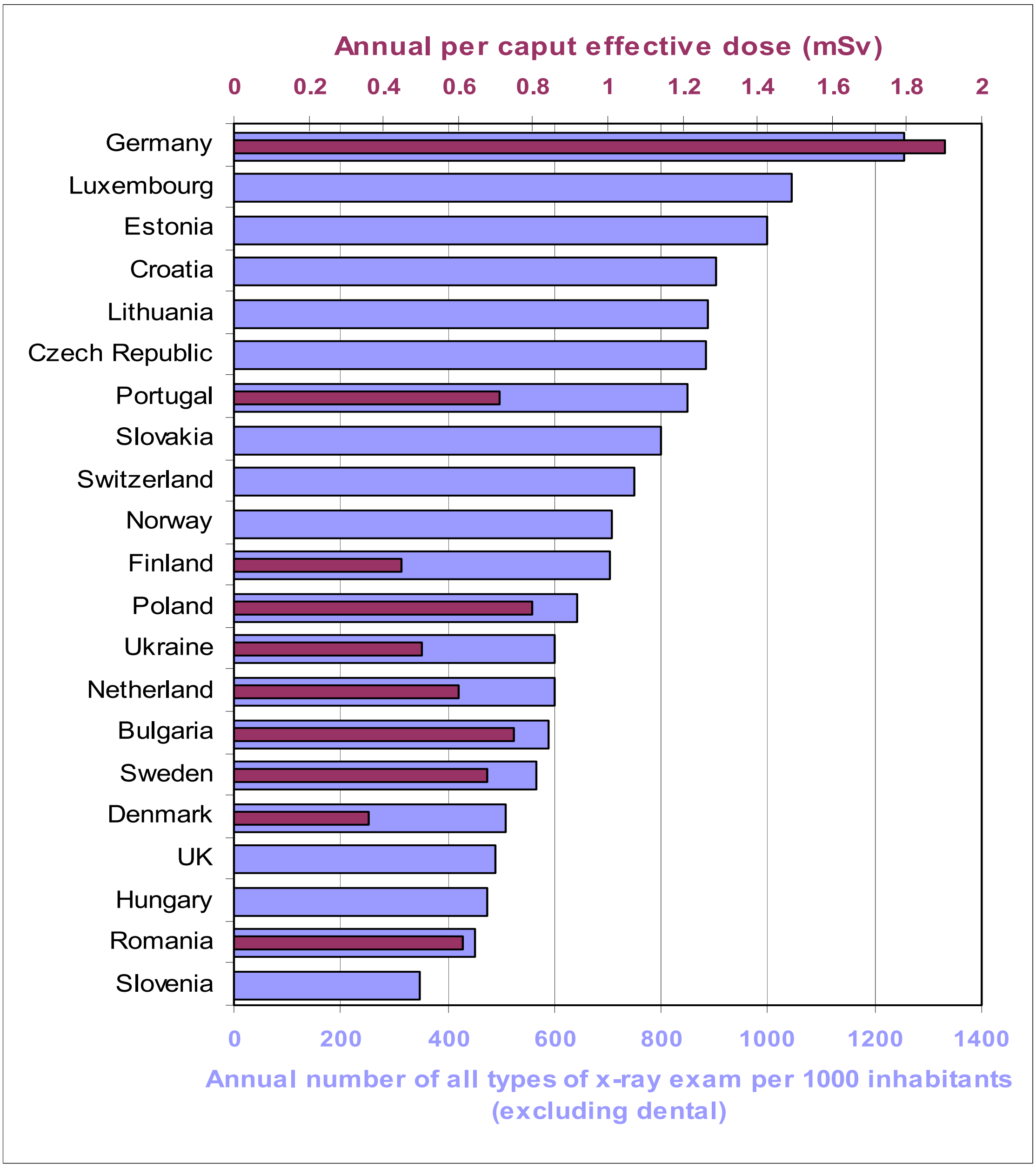
Country	Organisation in charge of population dose surveys
UK	Health Protection Agency (HPA), Radiation Protection Division, Chilton, Didcot, Oxfordshire, OX11 ORQ, United Kingdom (formerly the National Radiological Protection Board, NRPB)
CH	University Institute for Applied Radiation Physics, Grand-Pré 1, 1007 Lausanne, Switzerland Under the auspices of - Federal Office of Public Health (OFSP), Division Radioprotection, 3003 Berne, Switzerland
DE	Federal Office for Radiation Protection (BfS), Department of Radiation Protection and Health, Ingolstaedter Landstr. 1, 85764 Oberschleißheim, Germany
SE	Swedish Radiation Protection Authority (SSI), SE 171 16 Stockholm, Sweden
NO	Norwegian Radiation Protection Authority (NRPA), PO Box 55, N-1332 Østerås, Norway
NL	National Institute for Public Health and the Environment, Laboratory for Radiation Research, P.O. Box 1, 3720 BA Bilthoven, The Netherlands
FR	Institute of Radiation Protection and Nuclear Safety (IRSN), Radiation Protection and Human Health Division, BP 17, 92262 Fontenay-aux-Roses cedex, France
BE	Federal Agency for Nuclear Control (FANC), Control and Surveillance Department, Medical Applications Unit, Ravensteinstreet 36, 1000 Brussels, Belgium
DK	National Institute of Radiation Protection, Knapholm 7, DK-2730 Herlev, Denmark
LU	Ministry of Health, Division of Radiation Protection, Villa Louvigny, L-2120 Luxembourg, Luxembourg

These bodies are either part of a government department or ministry dealing with health or the Environment (i.e. Switzerland, Germany, Netherlands, Norway, Denmark, Luxembourg) or are non-governmental public bodies that may be partly funded by government but are independent of direct government control (i.e. UK, Sweden, France, Belgium). Some, but not all, of these bodies are responsible for preparing, licensing, inspecting and enforcing compliance with national regulations regarding radiation protection from medical exposures.

However, it was not until a few years after the EC Medical Exposure Directive (MED) of 1997 [EC, 1997] that Member States started to implement national regulations requiring any form of patient dose assessment. The previous 1984 EC Directive covering the radiation protection of patients [EC, 1984] did not require such assessments. Consequently all national patient dose surveys in Europe prior to 2000 were undertaken at the initiative of the official bodies listed above (or their predecessors) rather than in compliance with European Directives or national legislation.

Since 1955 the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has regularly monitored the medical uses of radiation as part of its periodic worldwide reviews of sources of exposure to ionising radiation. Over the past 30 years UNSCEAR has published 5 reports on *Sources and Effects of Ionising Radiation* (in 1977, 1982, 1988, 1993, and 2000) each with an Annex on *Medical Radiation Exposures.* Most of the above organisations have been responsible for providing UNSCEAR with as much data as was available on the extent of medical exposures in their countries at the time when these reports were being prepared. They have all provided data for the *Medical Radiation Exposures* Annex to the next UNSCEAR report that is currently in preparation.

The following Figure shows the annual number of all types of x-ray examination (excluding dental) per 1000 inhabitants (broad bars and lower axis), as reported from 21 European countries for the period 1991-1996 in the UNSCEAR 2000 report. On average the x-ray examination frequency was 717 per 1000 inhabitants, ranging from 348 to 1254 between these countries (a factor of 3.6). Only ten of these countries provided sufficient information to UNSCEAR to estimate the annual collective effective dose from all these x-ray examinations. The corresponding annual per caput effective dose is obtained by dividing the collective dose by the population of each country and is also shown on the following Figure (narrow bars and upper axis) for the ten countries concerned. Values can be seen to range from 0.4 mSv to 1.9 mSv (a factor of nearly 5), depending both on the examination frequency and the dose per examination in each country. One of the main reasons for initiating the DOSE DATAMED project was to examine the reasons for these wide variations between countries in both examination frequency and patient doses. The differences might be real or they might be at least partly due to the different techniques used and assumptions made in estimating population doses in each country. UNSCEAR is well aware that the reliability and completeness of the data available from different countries is extremely variable and strongly cautions against over-interpreting the data when making international comparisons.


Annual per caput effective dose (mSv)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Germany
Luxembourg
Estonia
Croatia
Lithuania
Czech Republic
Portugal
Slovakia
Switzerland
Norway
Finland
Poland
Ukraine
Netherland
Bulgaria
Sweden
Denmark
UK
Hungary
Romania
Slovenia
0
200
400
600
800
1000
1200
1400
Annual number of all types of x-ray exam per 1000 inhabitants (excluding dental)

4. National regulatory frameworks

Article 12 of the MED [EC, 1997] is headed 'Estimates of population doses'. It requires Member States to ensure that the distribution of individual dose estimates from medical exposure is determined for the population and for relevant reference groups of the population, as may be deemed necessary by the Member State.

Six of the DOSE DATAMED countries (Germany, Netherlands, Sweden, Norway, Belgium, Luxembourg) have 'deemed it necessary' to the extent that they have made the implementation of Article 12 a matter for national legislation. This is even the case in Norway, which is not an EU Member State. In all six of these countries the organisation shown in the previous table is identified in appropriate laws, decrees or ordinances that have been enacted since 2000 as being responsible for carrying out population dose surveys. In the Grand Duchy of Luxembourg's Ordinance of 2001 it is specified that evaluations should be made at least every five years. The regulations in the other five countries are not so prescriptive as to the required frequency of these evaluations.

In the other four DOSE DATAMED countries (UK, Switzerland, Denmark, France) the requirements of Article 12 have been interpreted as being covered by the periodic reviews of the collective effective dose to the population from diagnostic radiology that they have already instigated, without the need for specific national legislation. Despite the fact that Switzerland, like Norway, is not an EU Member State, it was one of the first countries to assess the population exposure from medical radiology and has continued to do so more frequently and more rigorously than almost any other country.

However, in all the DOSE DATAMED countries there are national regulations requiring radiological installations to regularly assess small samples of patient doses to establish and check compliance with Diagnostic Reference Levels (DRLs), as required by Article 4.2(a) of the MED, or as part of Quality Assurance (QA) programmes as required by Articles 4.3 & 8.2 of the MED. National collation of these local patient dose surveys can be a useful source of data for population dose assessments. Also, comparison of the national DRLs established in different countries for common types of x-ray examination can provide an insight into possible causes of variations in the collective population doses. However, care has to be taken in extrapolating from local surveys to the national picture and in converting the dose quantities that are measured in local surveys into effective doses for population exposure assessments in a reliable and recognised fashion. The methods used in the recent population dose surveys conducted by the DOSE DATAMED partners are discussed in section 8 of this report.

5. National healthcare systems in 10 European countries

Information was collected on those aspects of the healthcare systems operating in each of the 10 European countries that might have some impact on the level of provision of diagnostic radiology services and hence on the associated population exposure. These aspects include the level of funding for healthcare, the numbers of various types of medical practitioner in the country, the amount of medical imaging equipment available and details of which types of medical practitioner are allowed to refer patients for x-ray or to perform x-ray examinations. The information collected from the 10 countries between 2002 and 2005 is shown in Table 1 and was compared to see if it could account for some of the observed national differences in the frequency of x-ray examinations. It should be noted that the data in Table 1 does not necessarily relate to the same year in which the latest population dose survey was performed for each country.

Table 1: Some indicators of the national healthcare system

Country	UK	CH	DE	NO	FR	LU	SE	NL	DK	BE
Year	2002	2005 [3]	2002	2004	2002	2003	2003	2002	2004	2003
Population (millions)	60	7.2	82.5	4.61	61.4	0.448	9.0	16	5.2	10.36
% of GDP devoted to health care [1]	7.7%	11.2%	10.9%	8.7%	9.7%	6.2%	9.2%	9.1%	8.8%	9.1%
No. /million population of:										
All medical doctors	2200	3786	3600	2740	3346	2400	3300	3400 [9]	3650	3925
GPs [% of GPs who use x-rays]	665 [0%]	720 [50%]	568 [1%]	537 [0.5%]	1640 [<5%]	680 [0%]	540 [0%]	595 [0%]	775 [0%]	1729 [1%]
Dentists	420	603	780	966	674	803	900	580	841	~830
Radiologists	47	69	75	104	124	118	110	53	84	~147
Other doctors who often use x-rays[2]	165	100	~2400 [5]	255 [8]	250	303	500	~150	238	~397
[% of them who do use x-rays]	[50% =83]	[80%= 80]	[10%= 230]	[50%= 128]	[na%]	[75%= 227]	[15%= 75]	[na%]	[na%]	[59%= 234]
Radiographers	320	684	375	510	382	330	320	~260	235	~9.4 [12]
Diagnostic radiology physicists	6	1	~2	~2.2	0.1(1998)	4.1	6.5	~0.8	4.2	~5
No. /million population of :										
General radiog/fluoro systems	156	1186	365	203	220	228	170	144	232	211
Mammography x-ray sets	5	33	38	19	41	22	20	15	11	41
Dental x-ray sets	350	1209	880	1390	566	893	1400	350 [10]	1019	~380
CT scanners	6	26	30	27	10	26	18	12	16	29
MRI scanners	5	14	19	13	<5	10	9	8	-	9.4
Private / State practice (%):										
No. hospitals	10/90	25/75	11/49/40 [6]	14/86	68/32	80/20	5/95	0/100 [11]	10/90	69/31
No. patients	-	-	9/88	-	-	75/25	10/90	-	-	-
No. x-ray examinations	10/90	53/47 [4]	15/84	26/74	-	75/25	10/90	-	-	-
Radiologist payment system (%):			[7]							
Fixed salary	90%	90%	4% 56%	100%	34%	10%	100%	35%	100%	~10%
Per exam (national rates)	10%	10%	82% 37%			90%		65%		~65%
Per exam (own rates)			14% 7%							~25%

1. Total health expenditure for 2002 as % of Gross Domestic Product [OECD, 2004]
2. Doctors other than GPs, Dentists and Radiologists who are in specialities where x-rays are often used (i.e. Cardiologists, Gastroenterologists, Lung specialists (Pneumologists), Orthopaedic surgeons, Urologists, Vascular surgeons).
3. Except for the radiological equipment and the private/state practice, where the 1998 data is provided.
4. Dental exams excluded; when they are included the private/state proportions become 73%/27%.
5. Includes all specialities (other than GPs, Dentists and Radiologists), not only the 6 specialities listed in 2 above.
6. Split into 3 types of practice – Private/State/Not-for-profit organisations (e.g. religious organisations or charities)
7. 1st column = *all* doctors taking x-rays; 2nd column = only radiologists
8. The numbers in Norway refer to <70 year old medical doctors who are still working
9. Number of medical doctors that are entitled to practice, not the just the ones practising
10. Only those in dental practices
11. Private clinics (Independent Treatment Centres) have different definition in NL, not counting them in terms of 'hospitals'
12. Only those fully qualified with diploma of Bachelor in Medical Imaging

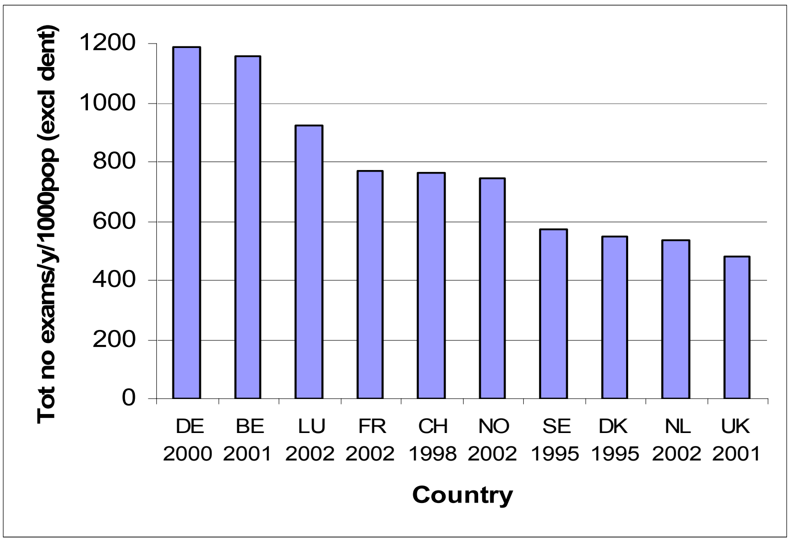
Table 1 (continued): Some indicators of the national healthcare system

Y = Yes N = No

Country	UK	CH	DE	NO	FR	LU	SE	NL	DK	BE
Who can refer patients for x-ray?										
Patient	N	N	N	N	N	N	N	N	N	N
Any doctor	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Dentists	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Nurses [1]	N	N	N	N	N	N	N	N	N	N
Radiographers [1]	N	N	N	N	N	N	N	N	N	N
Chiropractors	Y	Y	N	Y	Y	N	Y	N	Y	N
Official mammography screening programme	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Who can technically perform x-ray exams?										
GPs	N	Y [2]	Y [3]	Y	Y	N	Y [3]	N	N	Y [5]
Any doctor	N	Y [2]	N	Y	Y	N	N	N	Y	N
Only authorised doctors	Y	-	Y	-	-	Y	Y	Y	-	Y [5]
Dentists	Y	Y	Y [3]	Y	Y	Y	Y [3]	Y	Y	Y [6]
Dental assistants	Y	Y	Y	Y	N	Y	Y [3]	Y [4]	Y	N [7]
Nurses	N	N	Y [3]	N	N	N	Y [3]	Y [4]	Y [3]	Y [7]
Radiographers	Y	Y	Y	Y	Y	Y	Y [3]	Y [4]	Y	Y [7]
Chiropractors	Y	Y/N	N	Y	N	N	N	N	Y	N
Midwives	N	N	N	N	N	N	N	N	N	Y [7]
Others (specify):-		Med.Asst [2]	Med.Asst [3]							

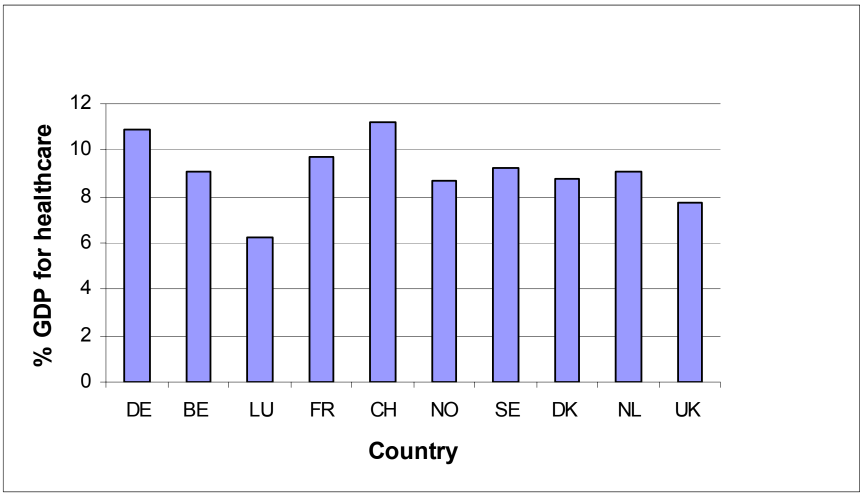
1. Not including nurses/radiographers working in A&E who may refer patients under specific protocols authorised by radiologists.
2. In CH GPs can perform low-dose exams (chest, limbs). Specialist doctors are trained to perform only the exams related to their speciality. Radiologists can perform all exams (in reality they don't do cardiology exams). Radiographers can perform all exams except fluoroscopy done exclusively by radiologists or specialist doctors. Medical assistants can perform low-dose exams (including spine and skull) after special training.
3. If authorised.
4. In the Netherlands only qualified doctors/dentists are allowed to perform x-ray exams. They can order any one who is competent (based on education and/or practice) to actually (technically) carry out the x-ray exam.
5. In Belgium GPs can perform X-ray exams (i.e. Chest & Limb radiographs). Radiologists can perform all types of X-ray exams, and other Specialists only those exams related to their speciality. Each Doctor (GP, Specialist) using ionizing radiation (in casu X-rays) has to be licensed by the authorities, but only granted to those who have followed a course in radiation protection at university level (75 hours: 40 hrs theoretical lessons, 35 hrs of practice).
6. Belgian Dentists (Master of dental sciences) can perform only dental radiography (intra-oral, panoramic). Has to be licensed by the authorities.
7. Dental Assts, Nurses, Radiographers and Midwives, can only perform x-ray exams when delegated by a physician/medical doctor, licensed for the use of X-rays, according to his/her instructions, and under his/her real control and responsibility. They must also follow a course in radiation protection (minimum 50 hours with at least 15 hours practical training).

Firstly, the total annual number of medical x-ray examinations performed in each country per thousand population (excluding dental x-ray examinations) is shown in the bar chart below. This information was obtained from the latest population dose surveys conducted in each country between 1995 and 2005, as described in the following sections of this report. The 10 countries can be broadly divided into 3 groups according to x-ray examination frequency. In the 1st group, Germany (DE), Belgium (BE) and Luxembourg (LU) perform 900-1200 examinations per 1000 population; in the 2nd group, France (FR), Switzerland (CH) and Norway (NO) perform 700-800 examinations per 1000 population; and in the 3rd group Sweden (SE), Denmark (DK), the Netherlands (NL) and the United Kingdom (UK) perform 450-600 examinations per 1000 population (about half the frequency of the highest group).



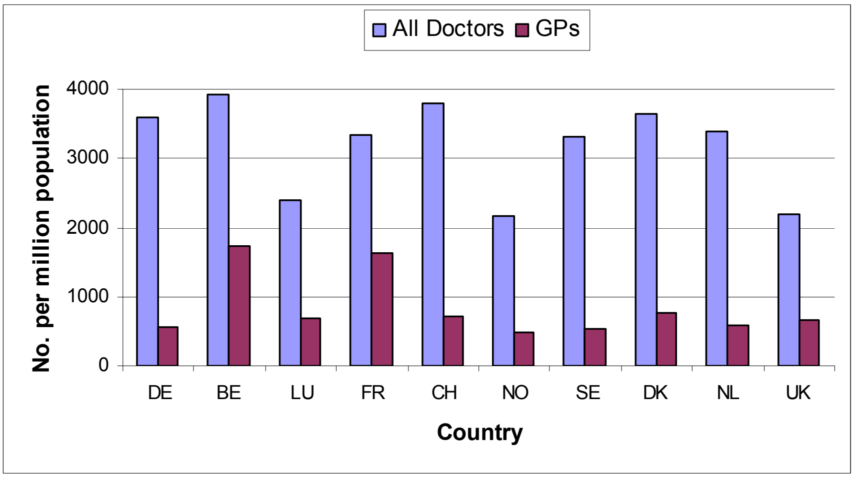
In the following bar charts showing information on the healthcare systems in each country from Table 1, the countries are presented in the same order of descending x-ray examination frequency as in the above bar chart.

Percentage of Gross Domestic Product devoted to healthcare



The percentage of the Gross Domestic Product (GDP) devoted to healthcare in each country was obtained from data published by the Organisation for Economic Co-operation and Development on total health expenditure in each country for 2002 [OECD, 2004]. It shows no discernible trend with x-ray examination frequency, but a significantly lower value for Luxembourg compared to the other countries.

Numbers of doctors per head of population



The number of medical doctors (all types) per million population is much lower for Luxembourg, the UK and Norway than for the other countries. The number of General Practitioners (GPs) per million appears to be considerably higher in Belgium and France than in the other countries but it can be seen from Table 1 that the percentage of them that use x-rays is very low in Belgium (1%), as it is in all other countries except Switzerland. Switzerland is exceptional in having half its GPs using x-rays. However, they tend to perform simple low-dose examinations (usually of the chest and limbs), so that although the frequency of these examinations will be higher in Switzerland, they are unlikely to produce a significant increase in the collective dose to the population.

Numbers of doctors in specialities where x-rays are often used

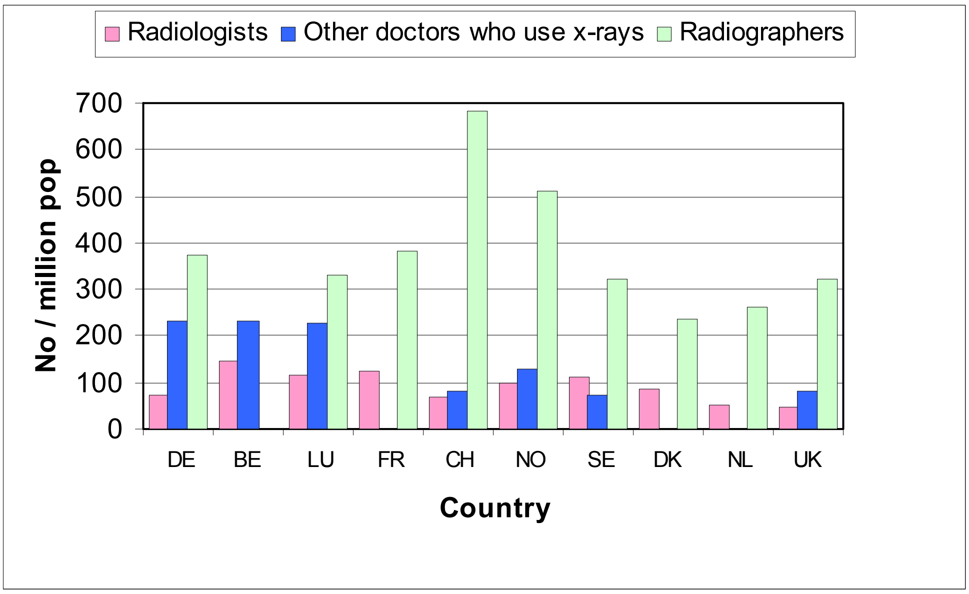
In order to understand the impact of the different healthcare systems on x-ray examination frequency in each country, it is important to distinguish four actions associated with x-ray examinations: the referral, the justification, the technical performance of an x-ray examination and the clinical evaluation of the images. According to the MED [EC, 1997] an x-ray examination should only be performed if a justification of the referral has taken place. The referrer (or prescriber) is required to provide adequate medical information to the practitioner who has clinical responsibility for the examination so that an informed decision on the justification of the x-ray examination can be made. There should always be a justifiable clinical indication for the examination and alternative diagnostic procedures that do not require ionising radiation, like magnetic resonance tomography or ultrasound imaging, should be considered if these have the potential to answer the clinical question adequately.

The practitioner who has clinical responsibility for the examination and its justification can be a radiologist or any other type of medical doctor, dentist or health professional, in accordance with national requirements. The referrer is usually a medical doctor or dentist. Patients are often referred by a general practitioner or a specialist doctor to a radiologist for the justification and technical performance and/or clinical evaluation of the examination (known as a "radiologist-referral"). Alternatively, non-radiologist doctors (e.g. orthopaedic surgeons, cardiologists, or dentists) can refer, justify, perform and clinically evaluate x-ray examinations (known as "self-referral"), after having received adequate training in the appropriate radiological procedures and radiation protection. In this case referral, justification, performance and clinical evaluation of the x-ray examination occurs at the same place by the same person. In all countries self-referral by dentists is common practice but in some countries self-referral by other types of non-radiologist doctor (e.g. Cardiologists, Gastroenterologists, Orthopaedic Surgeons, Lung

Specialists, Urologists, and Vascular Surgeons) takes place to a much larger extent than in other countries. Generally, self-referral by non-radiologist doctors of diagnostic imaging and interventional procedures tends to result in higher rates of x-ray imaging compared to radiologist-referral, especially when it takes place in private practice.

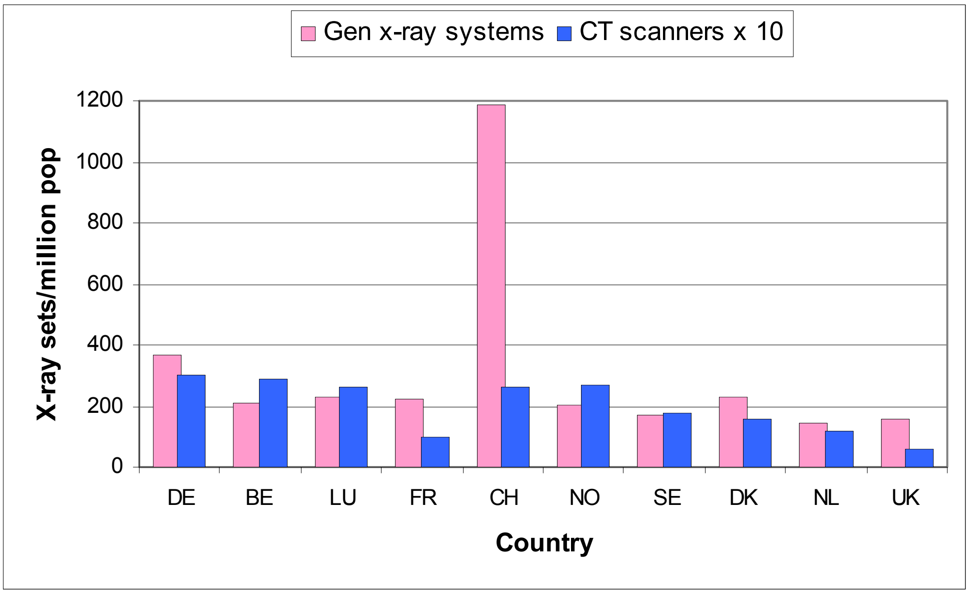
For example, in the UK, radiologists are involved in the justification, performance and/or clinical evaluation of the majority of medical x-ray examinations, but there are fewer radiologists per head of population in the UK than in most other countries as can be seen in the bar chart below. In contrast in Germany, only about 25% of all x-ray examinations in out-patients involve radiologists, and the other 75% are referred, justified, performed and evaluated by doctors who are specialists in a field other than radiology. The number of 'other' doctors (i.e. other than GPs, dentists or radiologists) who are thought to use x-rays, per head of population, in Germany, Belgium, and Luxembourg can be seen to be two to three times that in any other country from Table 1 (~230 per million population) and far more than the number of radiologists. The numbers of 'other' doctors thought to be using x-rays per million population are shown for those countries where an estimate was available in the bar-chart below. These estimates are very approximate and were not available in some countries. Nonetheless, the differences between countries in the numbers of radiologists and of other doctors performing x-rays examinations per head of population could well be responsible for the major national differences in the frequency of x-ray examinations.

The number of radiographers per head of population is also shown in the bar-chart below and appears to show no distinct trend with examination frequency between countries, but Switzerland appears to have considerably more than other countries.



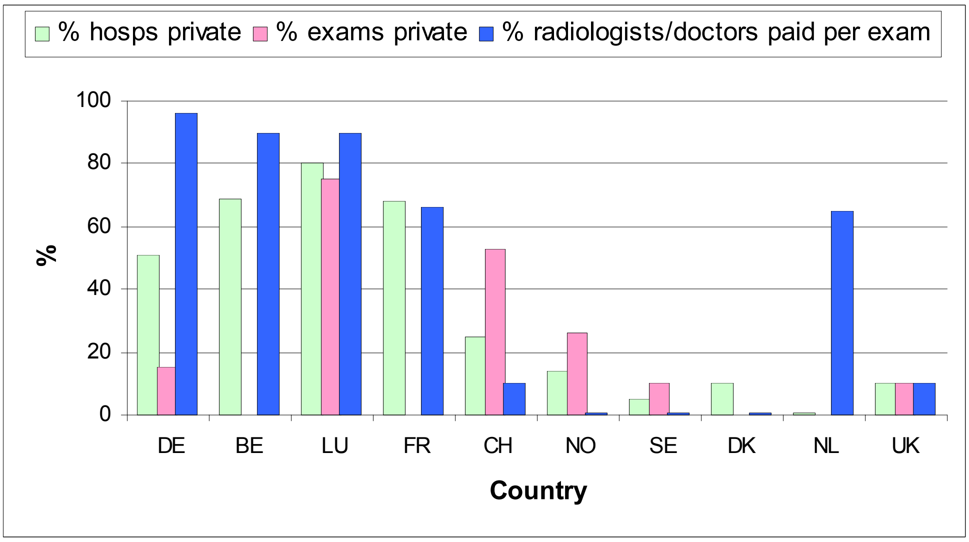
Amount of x-ray imaging equipment per head of population

Switzerland also appears to have considerably more in the way of numbers of general radiography/fluoroscopy imaging systems (i.e. all x-ray imaging systems other than those specifically designed for mammography, dental radiography or computed tomography) per head of population, as shown in the bar chart below. This large number of general x-ray sets is thought to be at least partly due to the large number of GPs (360 per million population) who take x-rays in Switzerland. For the other countries there is a general trend towards a reduction in the number of general x-ray systems per head of population as the x-ray examination frequency decreases. The same is true for the provision of CT scanners, with the high frequency countries (DE, BE and LU) having nearly 5 times the number of CT scanners per million population than the UK. However, Switzerland and Norway also have a high number of CT scanners per million population, but this does not apparently result in a high frequency of examinations. The widely scattered population in Norway with many parts of the country being relatively inaccessible could account for the high numbers of Norwegian CT scanners serving a small population.



Extent of private medical practice in each country

The extent of private medical practice in a country might be thought to have an impact on the frequency of x-ray examinations. The bar chart below shows the percentage of hospitals in each country that are independent of the State system (i.e. private) and the percentage of all x-ray examinations that are performed in private practice, where this information is available. It also shows the percentage of all radiologists or other doctors who use x-rays that are paid per examination rather than being on a fixed salary.



In Germany, 96% of all the doctors who perform x-ray examinations (and 44% of the radiologists) are paid per examination rather than being on a fixed salary. In Belgium and Luxembourg about 90% of radiologists/doctors are paid per examination and 70-80% of hospitals are privately run. This is in sharp contrast to Sweden, Denmark and the UK where 90-100% of radiologists/doctors are on a fixed salary and no more than 10% of hospitals or examinations are in private practice.

Who can refer patients for x-ray examination in each country?

Information on who can refer patients for x-ray examinations in each country is shown on the second page of Table 1. There is seen to be no variation between countries in the types of health professional who can refer patients, apart from chiropractors who are entitled to refer patients in 6 of the countries but not in the other 4. Since they are responsible for such a small fraction of the total radiology workload in any country, these differences will not have a significant impact on the population exposure. All countries have an official breast cancer screening programme using mammography, where asymptomatic women in a limited age range are invited to be screened. However, some of the screening programmes had not achieved complete national coverage at the time of the latest population dose survey, and these differences in coverage might have a small impact on the frequency of x-ray examinations in each country.

Who can technically perform x-ray examinations in each country?

Technically performing an x-ray examination is taken to involve only setting up the patient and operating the x-ray equipment to obtain the necessary images and not to include any clinical evaluation of the images. Information on who can technically perform x-ray examinations in each country is shown on the second page of Table 1 and some differences between countries are apparent. It is not current practice for GPs to perform x-ray examinations in the UK, Luxembourg, Netherlands or Denmark. In the other countries GP radiology is mostly limited to simple examinations of the chest and limbs but, as shown in a previous part of Table 1, it is only in Switzerland that a significant proportion of GPs (50%) actually indulge in this practice. Non-radiologist doctors can perform x-ray examinations in all countries but there is, at least, a formal requirement for them to be authorised and suitably trained. The nature of this authorisation and training varies from country to country, as does the degree to which it is tested and enforced by the appropriate authorities.

Dentists and dental assistants (under the supervision of dentists) can perform dental x-ray examinations in all countries, with the exception of dental assistants in France and Belgium. Nurses can perform x-ray examinations in Germany, Sweden, Netherlands, Denmark and Belgium but only when authorised to do so under the close supervision of a medical doctor and after suitable training. Chiropractors are allowed to conduct x-ray examinations in only the UK, Switzerland, Norway and Denmark but in Germany, Luxembourg, the Netherlands and Belgium they are neither allowed to refer patients to other doctors for x-ray examination nor to perform examinations themselves. Midwives cannot perform x-ray examinations in any country except theoretically in Belgium, but only if licensed and when delegated and supervised by a medical doctor who is authorised to use x-rays. In Germany and Switzerland "Medical Assistants" can perform 'low-dose' examinations if authorised by a medical doctor and after suitable training, but this practice is not allowed in any other country.

Naturally, radiographers (or radiological technologists) can technically perform x-ray examinations in all countries. The level of training for radiographers in diagnostic radiography varies between countries but is usually a 3 or 4 year course leading to either a (university) bachelor degree level qualification (UK, BE, FR, NL, DK, NO, SE) or a vocational qualification (DE, LU, CH up to 2006).

Healthcare providers of x-ray imaging

Information was also collected on the different types of organisation, hospital, clinic, institute, unit or practice that was authorised to provide x-ray imaging facilities in each country. Table 2 lists all potential types of provider of x-ray imaging facilities and indicates the approximate numbers of each type of provider in each country and whether they were included in the latest national survey of population exposure for that country or not. Aspects of these data that might influence the frequency of x-ray examinations in a country are discussed below.

In all countries radiology services are provided by State-run hospitals (including University hospitals) and private hospitals, but the proportions of each type and their share of the radiology workload differ markedly between countries. In a number of countries (but not all) radiology services are also provided by 'Private Radiology Institutes', 'GP Practices' or practices run by specialist doctors ('Specialist Practices') particularly those engaged in orthopaedics, cardiology, gastroenterology, urology and thoracic or vascular disease. These types of radiology service provider are particularly important in Switzerland where only 60% of medical x-ray examinations (excluding dental) are performed in hospitals and radiology institutes where radiologist-referral predominates. The other 40% are performed in practices where self-referral by non-radiologist doctors is the norm (27% in GP practices and 13% in other types of 'Specialist Practices'). In Germany the situation with respect to self-referral is similar to Switzerland, but with a higher percentage of specialist practices. In Sweden and Norway private radiology service providers exist, but these are run by radiologists. The UK and Denmark do not have any types of private institute or specialist practice where self-referral for x-ray examination takes place (apart from dental practices and chiropractic clinics).

There are no Chiropractic Clinics using x-rays in Germany, France, Sweden, the Netherlands, Luxembourg and Belgium, but 45-300 in Norway, Denmark, Switzerland and the UK. The extent of x-ray imaging practice in 'School Dental Services', 'Health Checks at Borders', 'Prisons', 'TB Screening Units' and 'Armed Forces Hospitals/Units' varies from country to country. But in all countries the contribution from these providers to the total frequency of x-ray exams will be insignificant.

Medical research exposures do not appear to have been explicitly assessed in any national surveys. It was thought that these will mostly be done in hospitals and would be either automatically included in the frequency data or, if not, would make only an insignificant contribution to the total collective dose and frequency.

Only Norway and Belgium had not included dental radiology conducted by dentists in 'Dental Practices' in their latest national surveys according to Table 2. This will have little impact on the collective dose but a big impact on the frequency of x-ray examinations, since dental x-rays expose the patient to very low effective doses but account for at least one third of all x-ray examinations in most countries. Norway has since made estimates for dental radiology to include in the Results section of Table 3 (see section 9).

Table 2: Healthcare providers involved with X-ray imaging

A = included in national survey
B = NOT included in national survey
(…) = No. of providers using x-rays in country

	Country	UK	CH	DE	NO	FR	SE	NL	DK	LU	BE
1	University Hospitals	A (in 2)	A (5)	A (in 2)	A (8)	A (29)	A (8)	A (8)	A (in 2)	B (0)	A (7)
2	Other State Hospitals	A (~1500)	A (209)	A (~1600+~500[4])	A (63)	A (1532)	A (~ 80)	A (~100) [5]	A (50)	A (5)	A (61)
3	Private Hospitals	A (~100)	A (71)	A (~500+~400[4])	A (10)	A (1373)	A (4)	B (a few) [6]	B (4)	A (4)	A (135)
4	Private Radiology Institutes	B (0)	A (85)	A	A (25)	A	A (30)	B	B (0)	B (0)	A
5	General Practices	B (0)	A (3910)	A	B (~50)	A	B (0)	B (0)	B (0)	B (0)	A
6	Specialist Practices [1]	B (0)	A (1409)	A	B (0)	A	B (0)	B (0)	B (0)	A (6)	A
7	Occupational Medicine	B (v. few)	A (9)	A	B (0)	B	B (0)	B (0)	B (0)	B (0)	B
8	Chiropractic Clinics	A (~300)	A (138)	B (0?)	B (210, 45 with x-ray sets)	B (0)	B (0)	B (0)	A (~100)	B (0)	B
9	Dental Practices	A (>10k)	A (3760)	A	B (4452 dentists)	A	A (2500)	A (~5500)	A (~3k)	A (360)	B (8450 dentists)
10	Dental Institutes	A (in 9)	A (33)	A	B	B	A (in 9)	A (in 9)	B (2)	B (0)	B
11	School Dental Services	B (0)	A (19)	B (0)	B (in 9)	B	B (0)	B (0)	A (~400)	B (0)	B
12	Health checks at borders	B (2)	A (1)	B (0)	B (0)	B	B (0)	B	B (0)	B (0)	B
13	Prisons	A (~100)	A (60)	B	B (0)	B	B (~3)	B [7]	B (0)	B (1)	A [10]
14	TB screening units	B (v. few)	A (14)	A (Fed. armed f.)	B (1)	B (0)	B (0)	A	B (0)	A (3) [9]	A [11]
15	Mammo screening units	A (~300)	A (~50 in 1,2,4)[2]	A (from 2006: 72)	A (25)	A	A (130)	A (~ 63)	A (6)	A (9)	A [11]
16	CT screening units	B (~10)	B (0)	B (0)	B (0)	B (0)	B (0)	B (0)	B (0)	B (0)	
17	Armed forces hosps/units	A (~10)	B (v. few) [3]	A	A (1-3)	A (9)	B (1)	B [8]	B (14)	B (0)	A/B[12] (1)
18	Med Research Exposures	A (in 2)	B (?)	B	B	B (0)	B (0)	B (?)	B (?)	B (0)	B

1. Iclude the following specialties:- Cardiology, Gastroenterology, Orthopaedics, Thoracic surgery (pneumology), Urology, Vascular surgery (angiography).
2. wiss breast cancer screening programmes are run in 5 French speaking cantons out of 23 (~50 radiologists involved).
3. wiss armed forces perform in total less than 200 X-ray examinations/year, mainly chest and limb radiography.
4. erman 'Prevention and Rehabilitation Centres'.
5. he number of organisations (merge of hospitals), not the locations.
6. rivate clinics have a kind of different definition in the Netherlands, they are not counted in terms of hospitals.
7. berculosis screening in prisons is performed by health services (included in the number of provider 14).
8. One army hospital is included in provider 2. One other clinic, field clinics and dental units of the army are not included.
9. Only for foreigners.
10. All; with the exception of only about 10 examinations per year.
11. For most of the examinations
12. Military personnel not included in survey but civilians are (for instance family members/relatives of the military personnel)

6. National strategies for assessing population doses from medical x-rays

There are three fundamental characteristics of medical x-ray exposures which have a large influence over the way that population doses are assessed:

- they are by far the largest man-made source of population exposure to ionising radiation in all developed countries,
- they involve very non-uniform exposures of the patient's body,
- they are not evenly distributed throughout the population.

UNSCEAR has been involved in international comparisons of medical exposures for over 50 years. The methods it has used for assessing patient and population doses from medical radiology have evolved considerably in this time as knowledge of the health effects of ionising radiation has increased. Earlier reports expressed patient doses in terms of the mean absorbed dose to just the few organs or tissues thought to be sensitive to radiation at the time (e.g. gonads and red bone marrow) and population doses were expressed in terms of the annual genetically significant dose and the annual per caput red bone marrow dose. In its most recent reports [UNSCEAR, 1993 and 2000] UNSCEAR has used effective dose [ICRP, 1991] as a convenient indicator of overall risk-related exposure of the patient from an x-ray examination, and population doses were expressed in terms of the annual collective effective dose to the entire population of a country or the annual per caput effective dose averaged over the entire population.

The effective dose (E) essentially takes account of non-uniform body exposures and the organs and tissues now known to be sensitive to deleterious radiation effects by estimating the average whole body dose that would result in the same total stochastic radiation risk. It therefore enables different sources of exposure that result in different dose distributions in the body to be compared in terms of a single risk-related dose quantity. The collective effective dose (S) takes account of the number of people exposed to a particular source by multiplying the average effective dose to the exposed group by the number of individuals in the group. The collective effective dose can be thought of as representing the total adverse health consequences of the radiation exposure of a population [ICRP, 1991], but only if the consequences are truly proportional to the effective dose for the population in question. Since the collective population dose depends on the size of the population, it is sometimes more useful to use the annual average per caput dose (i.e. the annual collective dose averaged over the entire population), particularly when studying trends in population doses with time or when comparing the population doses from different countries.

The relationship between effective dose and the probability of stochastic effects is among other things critically dependent on the age distribution of the exposed population. The age distribution of patients undergoing x-ray examination is generally skewed towards the elderly, for whom the lifetime risks of radiation-induced cancer are much reduced compared to the general population. Consequently collective effective dose estimates for medical exposures should **not** be used for assessing radiation risks (or detriment) to populations of patients by simple application of the nominal probability coefficients for radiation-induced cancer given by ICRP [ICRP, 1991 and 2007a], which have been derived for a general population.

Notwithstanding the above caveat, it is reasonable to use effective dose (and collective effective dose) to quantify medical exposures for the following purposes where only relative comparisons of the exposures of populations with similar age and sex distributions are being made.

1. To observe trends in the population dose from medical x-rays in a country with time.
2. To determine the contributions of different imaging modalities and types of examination to the total population dose from all medical x-rays.

3. To determine the relationship between the frequency of different types of x-ray examination and their contribution to the total population dose.
4. To determine whether there are any regional variations within a country in the frequency or collective doses from particular types of x-ray examination.
5. To compare the annual frequencies of x-ray examinations per head of population and the annual per caput doses from those examinations between countries.

All ten European countries represented in the DOSE DATAMED project have followed UNSCEAR practice in their most recent surveys and have assessed population doses from medical x-rays in terms of the annual collective or per caput effective dose. To assess the annual collective effective dose to the population of a country from medical x-rays requires knowledge of the total number of each type of medical x-ray procedure performed in the country in a year and the average effective dose received by patients from each procedure.

The next two sections will discuss and compare the methods used to assess the frequency of x-ray examinations and to estimate the typical effective doses received by patients from these examinations in the 10 DOSE DATAMED countries. Some important basic information about methods used and the results from the recent national surveys of population exposure from medical x-rays in each of the ten DOSE DATAMED countries is summarised in Table 3. At the bottom of the Table references are given to published reports describing these surveys, when these are available, and to the section of Appendix 1 where a brief account of the methods and results for the most recent national survey is given by the representative of the country in the DOSE DATAMED project.

Table 3: Basic data for national surveys of population dose from ten DOSE DATAMED countries

		UK	CH	NL	DE	FR
	Survey Dates					
1	Date (frequency)	2001	1998	2002 ('90)	2000	1999-2002
2	Date (doses)	1990-2001	1998	2002 ('90)	1992-2005	2001-2003
3	Population	60 million	7.1 million	16 million	82.3 million	61.4 million
	Methods					
4	Basic freq. data	Annual nos from 38 trusts in 2 different regions (16% of English exams)	Annual nos from 11 big hospitals. 2 week survey in 274 medium & small hospitals & 2787 practices	Annual nos from 90% of hospitals	Annual nos from health insurance (statutory + private) for about 80% of x-ray exams	Annual nos from health ins + stats of Health Estabs. 1999 - conv x-rays 2002 - CT & dental
5	Scaled up to whole country by	Total no. of x-ray exams per trust	No. of hospitals & practices with x-ray unit	No. of hospital admissions	Scaling factors to estimate in-patient data (2002 in-patient data available)	No scaling necessary
6	No. of exam types	Freq: 150 Dose: 150	Freq: 257 Dose: 257	Freq: ~18 broad categories Dose: 48	Freq: 90 Dose: 40	Freq: 110 Dose: 8
7	Age/sex data (yes/no)	No	Yes	Yes (for 2000)	Yes (in-patients)	No
8	Basic dose data [1]	ESD, DAP, CTDI from large UK surveys	ESD calculated from av. Swiss technique factors. CTDI values for Swiss CT scanners from literature.	ESD, DAP, CTDI (measured in 11 hospitals)	ESD calculated from technique factors. DAP (in selected hosps). CTDI, DLP (from national survey)	ESD, CTDI, DLP from DRL campaign
9	Source of E coefficients [2]	NRPB-R262 (r/fl) NRPB-R250 (CT)	ODS-60 (r/fl) CT-Dose (Danish)	PCXMC (r) NRPB-R262 (fl) NRPB-R250 (CT)	GSF 11/90 (r/fl) NRPB-R262 (r/fl) GSF 30/91 (CT)	NRPB-R262 EUR 16262 (CT)
	Results					
10	Total no. exams/y (incl. dentists)	43 million	9.5 million	13.7 million	146 million	59–72 million [3]
11	Total no. exams/y (excl. dentists)	29 million	5.4 million	8.7 million	97.6 million	41-53 million
12	Total no. exams/y/1000 pop (incl dentists)	716	1343	847	1775	964 – 1173 [3]
13	Total no. exams/y/1000 pop (excl dentists)	483	762	538	1187	664 – 873 [3]
14	Total no CT/y/ 1000 pop	30	46	37	89	68 – 98 [3]
15	Annual S from all exams (man Sv)	22,700	7100	7300	136,200	40,400 – 50,700 [3]
16	**Total annual S /head (μSv)**	**380**	**1000**	**450**	**1656**	**602 - 770 [3] [Av = 686]**
17	**CT annual S /head (μSv)**	**178 (47%)**	**280 (28%)**	**190 (42%)**	**721 (43%)**	**238 - 338 [3] [Av = 285] (42%)**
	References	Hart & Wall, 2002 Hart & Wall, 2004 Appendix 1.1	Aroua et al, 2002a Aroua et al, 2002b Appendix 1.2	Brugmans et al, 2002 Geleijns et al, 2004 Appendix 1.3	Brix et al, 2005 Nekolla et al, 2005 Appendix 1.4	Scanff et al, 2005 Appendix 1.5

1. ESD = Entrance surface dose. DAP = Dose-area product (or KAP, Kerma-area product).
   CTDI = CT dose index. DLP = Dose-length product (CT).
2. r = radiography. fl = fluoroscopy.
3. Depending on the low or high hypothesis

Table 3 (cont.): Basic data for national surveys of population dose from ten DOSE DATAMED countries

		NO	SE	LU	BE	DK
	Survey Dates					
1	Date (frequency)	2002	1995	2002	1996-2002	1995
2	Date (doses)	1985-1995	1995	-	2000 -2005	1995
3	Population	4.6 million	8.8 million	430,000	10.2 million	5.1 million
	Methods					
4	Basic freq. data	Annual nos from all hosps & clinics (excl. dentists)	Annual nos from licence holders covering 25% of population.	Annual nos from Nat Health Ins (99% survey)	Annual nos from Nat Health Ins Inst (97-100% survey)	Directly from national hosps. Chiro–39 clinics (95% survey)
5	Scaled up to whole country by	No scaling necessary	Multiply by 4	No scaling necessary	No scaling necessary	Multiply by 1.05
6	No. of exam types	Freq: 250 Dose: 54	Freq: 15 Dose: 15	Freq: 250	Freq: ~130 Dose: ~15	Freq: 118 Dose: 118
7	Age/sex data (yes/no)	No	Yes (Age: 0-15, 16-40, >40)	Yes (5y bins)	Only CT (0-15, 10y bins, >85)	Yes (10y bins)
8	Basic dose data [1]	DAP, CTDI (national surveys)	DAP, CTDI (measured in local hosps - 6% of licence holders)	No measurements	ESD, DAP (measured in 37 centres)	DAP (measured in 20 hospitals)
9	Source of E coefficients [2]	NRPB-R262 (r/fl) NRPB-R250 (CT)	NRPB-R262 (r/fl) 'Practical CTDI'(CT)	E values taken from literature for LU and other countries	NRPB-coeffs & E values from UNSCEAR 2000 for other countries	Danish M/C code based on MCNP & GSF phantom
	Results					
10	Total no. exams/y (incl. dentists)	5.26 million	11.5 million	564,502	No dental data	6.8 million
11	Total no. exams/y (excl. dentists)	3.38 million	5.1 million	397,239	11.9 million	2.8 million
12	Total no. exams/y/1000 pop (incl dentists)	1156	1300	1313	No dental data	1332
13	Total no. exams/y/1000 pop (excl dentists)	742	570	924	1160	549
14	Total no CT/y /1000 pop	104	40	135	116	24
15	Annual S (man Sv)	5009	6000	852	17,950	2411
16	**Annual S /head (μSv)**	**1100**	**680**	**1822**	**1770**	**463**
17	**CT annual S/head (μSv)**	**642 (58%)**	**220 (32%)**	**993 (55%)**	**890 (50%)**	**173 (37%)**
	References	Olerud et al, 1997 Börretzen et al, 2007 Lysdahl et al, 2007 Appendix 1.6	UNSCEAR 2000 Appendix 1.7	Shannoun et al, 2006 Appendix 1.8	Appendix 1.9	UNSCEAR 2000 Appendix 1.10

1. ESD = Entrance surface dose. DAP = Dose-area product (or KAP, Kerma-area product).
   CTDI = CT dose index. DLP = Dose-length product (CT).
2. r = radiography. fl = fluoroscopy.

7. Methods for assessing the frequency of x-ray examinations

The methods used in each country for assessing the annual frequency of x-ray examinations are summarised in rows 4-7 of Table 3. They basically fall into 2 types:

a) Annual numbers of examination are obtained directly from a sample of hospitals, clinics or practices and then scaled up to cover the whole country.
b) Annual numbers of examinations are obtained from central statistics held by government departments or insurance companies for a large proportion of radiology practice in the country and then rounded up to cover all radiology practice in the country.

The UK, Switzerland, Norway, Netherlands, Sweden, and Denmark used method a). In the UK survey, data from the radiology information systems (RIS) from 38 hospital trusts in two different regions in England were collected and analysed. They contained detailed information from which the annual numbers of about 150 different types of x-ray examination could be obtained for these 38 trusts, which carried out about 16% of all x-ray examinations in England in the survey year (1997/98). In the Swiss survey a questionnaire was sent to about 3000 healthcare providers who perform x-ray examinations, including large and medium sized hospitals, dental surgeries, chiropractic clinics and GP practices. Information on the annual numbers of about 250 different types of examination was obtained, which included details of patient age and sex. The frequencies of examinations for the whole of the UK and Switzerland were derived by scaling up these two sample surveys in different ways. In the UK, Department of Health statistics on the total annual number of x-ray examinations performed in every hospital trust in England were used to scale up the sample data to the whole of England. Estimates for Wales and Northern Ireland were based on similar statistics from the devolved administrations and for Scotland on simply the relative size of its population. In Switzerland the numbers of examinations seen in each sample of hospitals, surgeries, clinics or practices were scaled up according to the total number of such healthcare providers with x-ray facilities in the whole country.

In the Norwegian survey information was obtained on the annual numbers of 250 types of x-ray examination from the radiology information systems (RIS) in all the 131 hospitals and clinics performing diagnostic radiology in the country. This was a very complete survey, so no scaling was necessary to derive total numbers for the whole country. In the Netherlands, annual frequencies for just 18 categories of x-ray examination were collected through annual surveys where about 90% of the hospitals in the country responded. In Denmark, frequency data for the latest survey in 1995 were obtained directly from about 95% of Danish hospitals for 118 types of x-ray examination and were scaled up to the whole country by multiplying by 1.05. The latest Swedish survey in 1995 obtained information by questionnaire on the frequencies of only 15 types of x-ray examination from radiological services (licence holders) covering about 25% of the Swedish population. These were simply multiplied by four to derive numbers for the whole country.

Germany essentially used method b) for out-patients and a variation of method (a) for in-patients. Information on annual frequencies of x-ray procedures for out-patients was obtained mainly from two national health insurance associations (state and private) for about 90 types of x-ray examination (grouped into 19 categories) and covering about 80% of the total number. For in-patients, method a) was used by observing the in-patient to out-patient ratios for the various examination categories in a sample of German hospitals for the year 2002. About 20% of x-ray examinations in 2002 took place in German in-patient facilities.

The other three countries used variations of method b). In France, examination frequency data was obtained from the national health insurance company for private practice (CNAM) and from national statistics of public health establishments (SAE). The two sources provide 100% coverage of national practice for about 110 types of x-ray examination, but there is an unknown amount of overlap between the two systems leading to a range of values being quoted in the final estimates, based on a 'low' and a 'high' hypothesis (see results in Table 3). The average of these two extreme values has been used in the analyses discussed later in this report. In Luxembourg and Belgium frequency information is available from health insurance data covering practically 100% of national practice, so no scaling up is required. Data on 250 types of examination was available in Luxembourg and about 130 types in Belgium.

It can be seen from the above that some countries had frequency data for over 200 individual examination types but others had it only for a much smaller number of examinations (e.g. 15 for Sweden) or only for a small number of broad categories of examination (e.g. the Netherlands). The ways in which individual examinations were described and grouped also differed markedly from country to country. The impact of these differences on the accuracy of the frequency data and the resulting population dose estimate in each country is discussed in detail in Appendix 2. In summary it can be said that:-

1. The uncertainties in the frequency estimates for some of the examinations making major contributions to the collective dose can be large (5%-50%).
2. Each one will have only a small impact on the accuracy of the total frequency estimate for all examinations together, which was found to lie between ±1.5% and ±6% (at the 95% confidence level) for the three countries studied.
3. Although uncertainties in both the frequency and dose estimates for some individual examinations can be high their impact on the accuracy of the estimate of the total collective doses from all examinations together is much smaller (7% - 20% in the three countries studied).

8. Methods for assessing patient doses

The methods used in each country for assessing patient doses are summarised in rows 8 & 9 of Table 3. For all countries the aim was to estimate a typical (average) effective dose (E) value, as defined in the 1990 recommendations of the ICRP (ICRP, 1991), for each type of x-ray examination. Three basic methods had been used:

a) Measure doses to patients for selected types of x-ray examination in a sample of hospitals in the country and convert them to E.
b) Calculate doses from technique parameters used for selected types of x-ray examination at a sample of hospitals in the country and convert to E.
c) Take typical E–values for selected types of x-ray examination directly from the published literature in the same country or in other countries.

For radiographic and fluoroscopic X-ray examinations (not CT) method (a) involving direct dose measurements on patients was used by 8 countries - the UK, Netherlands, Germany, France, Norway, Sweden, Denmark and Belgium. The selection of examination types was different for each country, as was the number of hospitals, clinics or practices where measurements were made. However, all countries gave priority to those types of x-ray examination which are either frequent or make a large contribution to the collective dose. For example, Belgium used method (a) in 20 interventional radiology centres between 2003 and 2005, but used method (b) in an earlier survey (2000) for some other important examinations.

Switzerland used method b) for all examinations and calculated patient doses from the observed technique parameters such as x-ray tube voltage, current and exposure time. The typical technique parameters were established for 257 types of x-ray examination from data collected from 8 major Swiss hospitals. Luxembourg did not carry out any patient dose measurements in its latest survey but relied entirely on method c) using published effective dose values mostly from Germany and Switzerland, which were thought to have similar radiology practices. In most other countries method c) was used for those types of examination for which doses were not available using methods a) or b).

For CT examinations a mix of method a) and b) was used by all countries except Luxembourg which again used method c). Most countries measured one of the CT dose index quantities (see below) on a sample of CT scanners (or used published values for the same types of scanner), collected information on the scan parameters used for a number of common CT examinations and used appropriate Monte Carlo based software to convert this information into E.

All countries using method a) or b) had measured or calculated patient doses in terms of one or more of the following practical dose quantities. These are the 'application specific dose quantities' as defined in ICRU Report 74 [ICRU 2005]. The new ICRU symbol for each quantity is shown in square brackets [ ] below, but the abbreviations commonly used for these quantities in the recent national surveys under discussion are shown in round brackets ( ) and are retained for the rest of this report.

Incident absorbed dose or Incident air kerma [$K_{a,i}$]:

The absorbed dose to air (or the air kerma) measured on the central axis of the x-ray beam at the point where it enters the patient or phantom, not including backscattered radiation.
Units: mGy.

Entrance surface dose (ESD) or Entrance surface air kerma (ESAK) [$K_{a,e}$]:

The absorbed dose to air (or the air kerma) measured on the central axis of the x-ray beam at the point where it enters the patient or phantom, including backscattered radiation.
Units: mGy.

Dose-area product (DAP) or air kerma-area product (KAP) [P_{KA}]:

The dose-area product (or air kerma-area product) is the integral of the absorbed dose to air (or the air kerma) over the area of the x-ray beam in the plane perpendicular to the beam axis.
Units: Gy cm^2

CT Dose Index (or CT air kerma index) measured free in air ($CTDI_{air}$) [C_K]:

$CTDI_{air}$ is the integral of the absorbed dose to air profile (or the air kerma profile) along the axis of rotation of the CT scanner, for a single rotation, divided by the total nominal detector collimation in the longitudinal direction (equals the nominal slice thickness for single slice scanners).
Units: mGy

Weighted CT dose (or air kerma) index measured in a phantom ($CTDI_W$) [$C_{K,PMMA,w}$]:

$CTDI_W$ is the weighted sum of the CTDI measured in the centre (c) and periphery (p) of a 16 cm (head) or a 32 cm (trunk) diameter cylindrical polymethylmethacrylate (PMMA) phantom.

$CTDI_W = 1/3\ CTDI_C + 2/3\ CTDI_P$
Units: mGy

$CTDI_W$ provides an indication of the average absorbed dose (or air kerma) in the central slice of a series of contiguous scans of the phantom.

Volume CT dose index measured in a phantom ($CTDI_{VOL}$)

$CTDI_{VOL}$ is the $CTDI_W$ corrected for the CT pitch factor (the CT pitch factor is the ratio of the distance moved (Δd, mm) by the patient support in the z-direction between consecutive serial scans or per 360º rotation for helical scanning, and the product of the number of simultaneous tomographic sections N and the nominal section thickness T (i.e. the beam collimation, mm)).

$CTDI_{VOL} = CTDI_W$/pitch factor
Units: mGy

$CTDI_{VOL}$ provides a rough indication of the average absorbed dose (or air kerma) over the scanned volume in the patient.

CT Dose-length product (DLP) [$P_{KL,CT}$]

DLP is the product of the $CTDI_{VOL}$ and the total scan length along the patient in the axial direction for a particular CT examination.
Units: mGy cm

All countries apart from Switzerland had used conversion coefficients based on Monte Carlo (M/C) calculations to derive effective doses from the measured or calculated doses. Mean values of the measured or calculated practical dose quantity for a nationally representative sample of patients were converted into effective doses using coefficients derived by simulating typical exposure conditions for each type of x-ray examination on a mathematical phantom representing an average adult patient. Thus mean effective doses were derived for each type of x-ray examination, which would be combined with information on the frequency of each type of examination to obtain the collective effective dose.

It was assumed that the mean effective dose for children from a particular type of x-ray examination was the same as that for adult patients. This was justified in view of the fact that, if the exposure parameters are properly adjusted according to the size of the patient, the effective doses for children and adults should be fairly similar. Also, since only a small fraction of x-ray examinations involve children and these are mostly low-dose examinations, they will have only a small impact on the total collective dose from medical x-rays.

Most countries used M/C coefficients developed by NRPB for radiographic and fluoroscopic examinations [NRPB-R262: Hart et al, 1994] and for CT examinations [NRPB-R250: Jones et al, 1991]. Germany also used M/C coefficients developed at GSF in Munich for radiographic/fluoroscopic examinations [GSF 11/90: Drexler et al, 1990] and for CT examinations [GSF 30/91: Zankl et al, 1991]. The Netherlands also used PCXMC developed in Finland [Tapiovaara et al, 1997] and Denmark used a M/C code developed at the Danish National Institute of Radiation Hygiene. The size of the mathematical phantom and the shapes and positions of all the organs required for effective dose calculations are very similar in all of these M/C codes. Published comparisons of these four sets of M/C conversion coefficients [e.g. in ICRU, 2005] have shown sufficient agreement with each other not to invalidate comparisons of the effective doses calculated in different countries using the different sets of M/C coefficients.

Switzerland used conversion coefficients for radiographic and fluoroscopic examinations derived by a semi-empirical method that were available in a software package called ODS-60. This package includes a gender and size adjustable phantom and has the ability to match the exposure conditions closely to those used in clinical practice on real patients of any size. However, there are some significant differences between the shape, size and location of organs in the ODS-60 phantom and those used in the M/C based systems. Substantial differences have been reported in the effective doses calculated by the ODS-

60 system and the M/C based systems for some examinations [Rannikko et al, 1997; Mechtel, 1999].

Appendix 2 contains a detailed discussion of the impact of the different methods for estimating mean effective doses for x-ray examinations (particularly the different samples of examination types and hospitals where measurements were made) on the accuracy of the patient dose data and the resulting population dose estimate in each country. In summary it can be said that:-

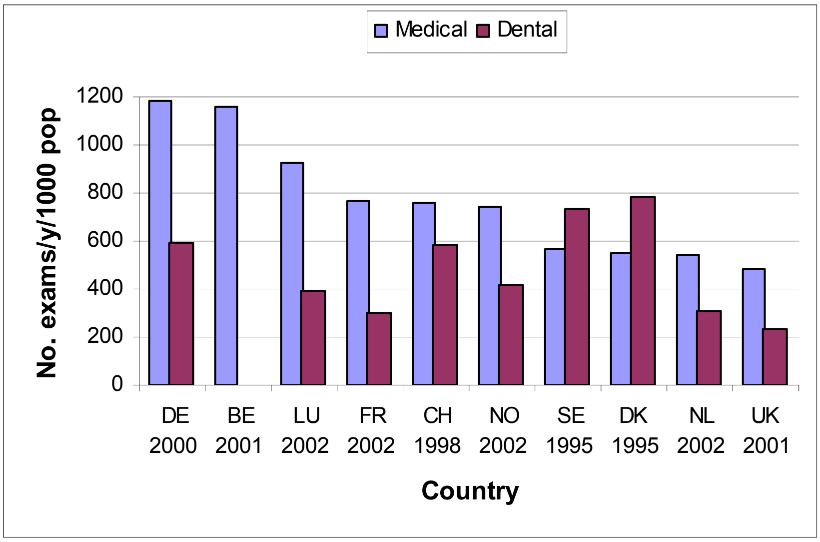
1. There are substantial uncertainties in the mean effective dose estimates for x-ray examinations in all countries. Uncertainties can lie in the range of 20-50% even when they are based on extensive surveys of current radiology practice in the country concerned, and can rise to a factor of two or three if they are simply based on published data from another country.
2. Although uncertainties in the dose estimates for some individual examinations can be high their impact on the accuracy of the estimate of the total collective dose from all examinations together is much smaller (7% - 20% in the three countries studied).

9. Results

9.1 Overall results

The overall results concerning the total annual frequencies of x-ray examinations and the annual collective and per caput effective doses from all x-ray examinations and from all CT examinations in each country are summarised in rows 10-17 of Table 3.

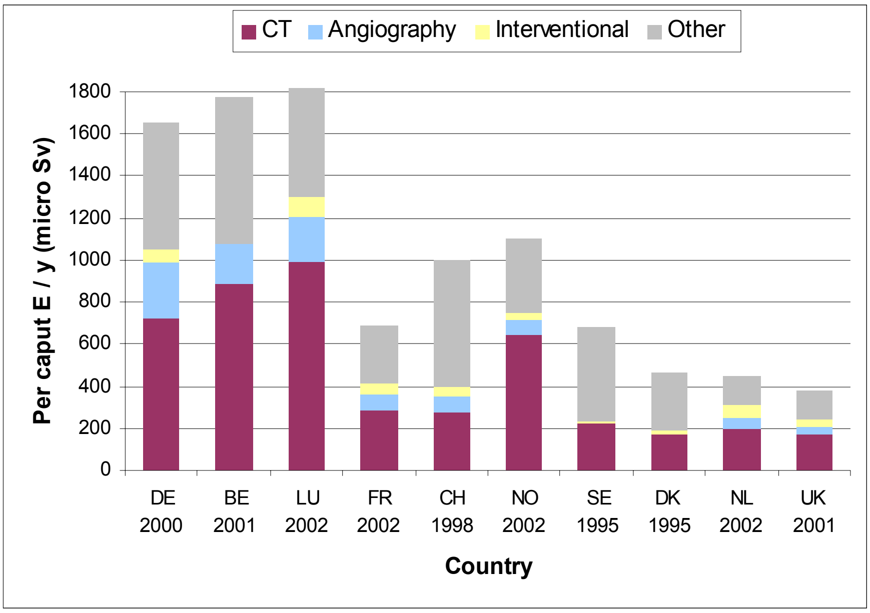
The total annual number of medical and dental x-ray examinations per thousand population in each country is shown in the bar-chart below. Dental x-ray examination frequency was not available for Belgium.



The 10 countries can be broadly divided into 3 groups according to the medical x-ray examination frequency. In the 1st group, Germany, Belgium and Luxembourg perform 900-1200 examinations per 1000 population; in the 2nd group, France, Switzerland and Norway perform 700-800 examinations per 1000 population; and in the 3rd group Sweden, Denmark, the Netherlands and the United Kingdom perform 450-600 examinations per 1000 population (about half the frequency of the highest group).

There is a large variation between some countries in the frequency of dental radiology in comparison with medical radiology. Dental radiology accounts for about one third of all x-ray examinations in all countries except Switzerland where it is 43% and Sweden and Denmark where it is over one half. However, the effective doses associated with dental radiology are very low, so this large variation in dental examination frequency will not have a significant impact on the total collective doses from all x-ray examinations in each country.

The total collective effective doses to the populations of each country from x-ray examinations are best compared in terms of the per caput effective dose (i.e. the annual collective dose averaged over the entire population). The total annual per caput effective dose from all medical and dental x-ray examinations is shown for each country in the bar-chart below with the contributions from CT, angiography and interventional procedures shown separately, where available. Separate interventional data were not available for Belgium (apart from PTCA alone) and separate angiography data were not available for Sweden and Denmark, but in each case are included in the 'other' examinations. The countries are still presented in the order of total medical x-ray examination frequency.



The total annual per caput E values are seen to range from 1820 μSv for Luxembourg to 380 μSv for the UK (a factor of 4.8). The three high examination frequency countries (DE, BE and LU) also show substantially higher per caput E values than any other country and the four low frequency countries (SE, DK, NL and UK) remain at the bottom end of the average population dose league table. There is a difference of about a factor of four in the average population dose between the three highest countries and the three lowest countries. France appears to have a relatively low total per caput E value in relation to its total x-ray examination frequency, suggesting that the estimated mean effective doses for some important examinations in France are lower than those for other countries with similar examination frequencies (see section 9.2).

CT is a major contributor to the total population dose from all x-ray procedures in all countries, ranging from nearly 60% in Luxembourg and Norway to about 30-40% in Switzerland, Sweden and Denmark. However, it must be realised that the Swiss, Swedish and Danish surveys were conducted in 1998 and 1995 whereas the Luxembourg and Norwegian surveys were conducted in 2002, by which time the frequency of CT examinations and their contribution to population dose had increased substantially in all countries.

Angiography and interventional procedures also involve relatively high patient doses and the latter have been increasing in frequency in most European countries over recent years. Together they are seen to contribute between 10% (Norway, 2002) and 26% (Netherlands, 2002) of the total population dose from all medical x-ray procedures in the above bar-chart. Angiography and interventional radiology are responsible for over 300 μSv per caput effective doses in Germany and Luxembourg (and probably in Belgium as well), which is equivalent to about 80% of the total per caput dose from **all** x-ray procedures in the UK.

9.2 Results for examinations making major contributions to the collective population dose

To investigate the reasons for the large national differences in the average population dose from all medical and dental x-ray procedures, those examinations or interventional procedures making major contributions to the collective dose have been identified and studied in detail.

The following 20 types of examination or procedure were consistently found to be amongst the highest contributors to the collective effective dose in all ten DOSE DATAMED countries:

Plain film radiography (no contrast medium)	Radiography/fluoroscopy (usually with contrast)	Computed tomography	Interventional radiology
1. Chest	8. Barium meal	13. CT head	20. PTCA
2. Cervical spine	9. Barium enema	14. CT neck	
3. Thoracic spine	10. Barium follow	15. CT chest	
4. Lumbar spine	11. IVU	16. CT spine	
5. Mammography	12. Cardiac angiography	17. CT abdomen	
6. Abdomen		18. CT pelvis	
7. Pelvis and hips		19. CT entire trunk	

Since the collective population dose is influenced by both the number of examinations and the dose per examination, information on both these factors for these 'Top 20 Exams' will be analysed to help explain the differences in collective dose between countries. Detailed frequency and dose results for each of these 'Top 20 Exams' are summarised in Appendix 3, Tables A3.1 to A3.10 for each country, respectively. Data for 'All CT' examinations, 'All Angiography' examinations and 'All Interventional' procedures are also included in the tables. The 'Top 20 Exams' contributed between 50-70% to the total frequency (excluding dental x-ray examinations) and between 70-90% of the total collective effective dose from all medical x-ray procedures in each country. When all CT, all angiography and all interventional procedures were included, these percentages rose to 60-70% and 90-98% respectively, as seen in the Table below.

Exam types or groups	**Country**									
	LU	BE	DE	NO	CH	SE	FR	DK	NL	UK
	% of total frequency									
Top 20 exams	62	68	61	68	58	72	64	49	62	63
Top 20 + All angio + All CT + All interventional	65	70	62	70	60	73	66	-	64	65
	% of total collective effective dose									
Top 20 exams	76	-	86	86	84	91	87	79	68	82
Top 20 + All angio + All CT + All interventional	91	92	93	95	90	94	98	-	90	93

Different aspects of the data in Tables A3.1 to A3.10 are analysed in the following sections.

9.2.1 Data on all 'Top 20 Exams' in three countries

Figure 1 shows the annual number of examinations per 1000 population, the mean effective dose per examination, and the annual collective effective dose per 1000 population (from left to right) for each of the Top 20 Exams for three countries – Germany, Switzerland and the UK. These three countries were chosen for this initial analysis because they represent a high, an intermediate and a low examination frequency country; and they have undertaken some of the most thorough surveys in recent years (see Table 3 and Appendices 1 & 3). In particular, recent dose estimates have been made for most of the 'Top 20 Exams', based on fairly representative surveys of actual radiology practice in each of these countries.

In Figure 1, the 'Top 20 exams' are grouped into three categories of examinations –

1. 'plain film radiography' (upper panels).
2. 'radiography/fluoroscopy, including interventional' (middle panels).
3. CT examinations (lower panels).

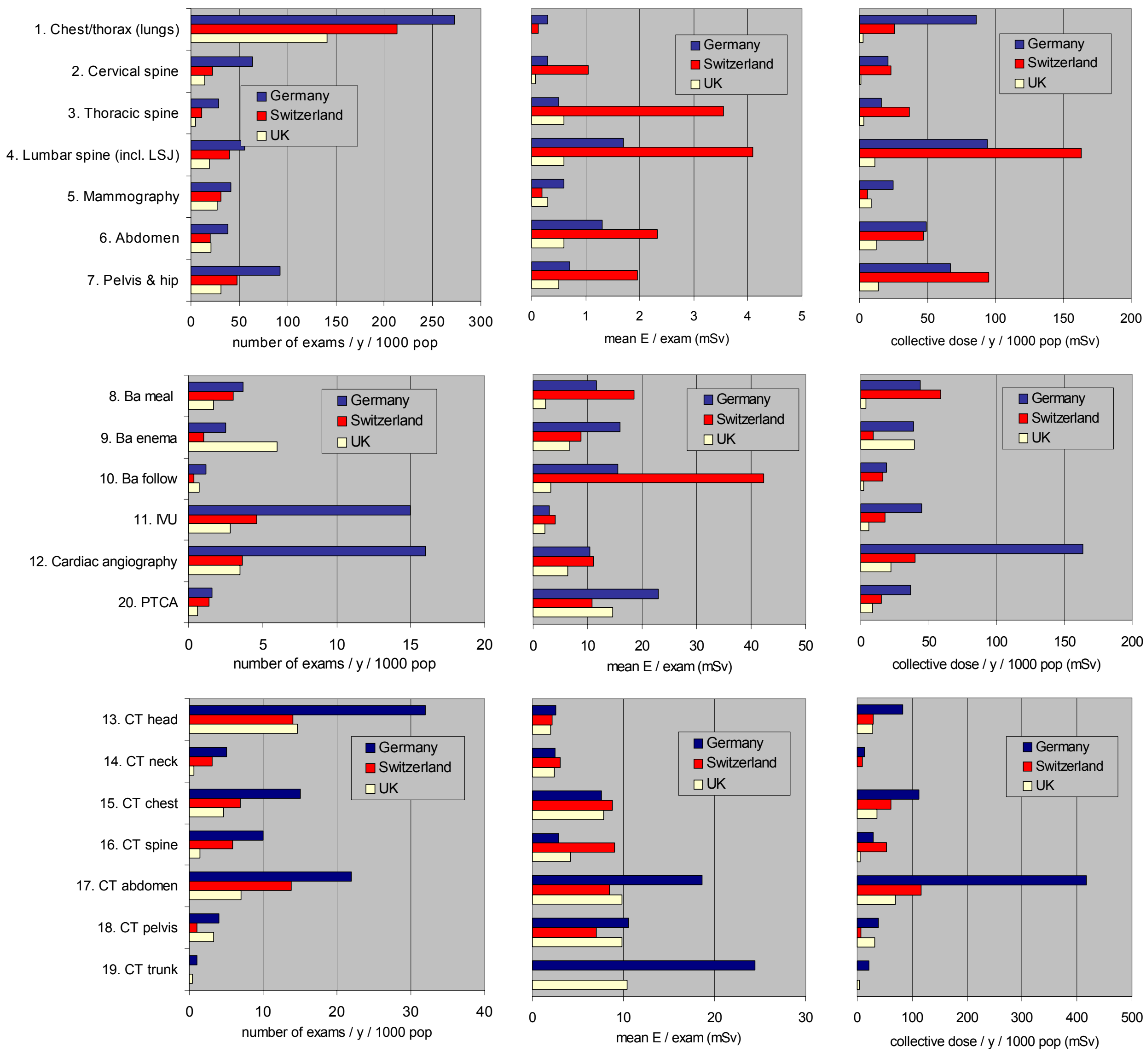


FIGURE1 Frequency and dose data for the 'Top 20 exams' in Germany, Switzerland and the UK

In the first category (plain film radiography), the frequency of all 7 exams is, not surprisingly, highest for Germany and lowest for the UK with Switzerland in between. The mean E per exam values, however, are highest for Switzerland for 5 of the 7 exams and highest for Germany for the other two (chest and mammography), the UK having the lowest doses by far for all but thoracic spine exams and mammography. The most striking peaks in the bar-charts are observed for examinations of the chest, of the lumbar spine and of pelvis/hip:

Chest: the number of examinations per 1000 population for Germany is about twice that for UK, Switzerland being intermediate. However, the differences between the mean effective doses between the countries are even more pronounced (although this is difficult to see on the bar-chart), the values for Germany/Switzerland being more than a factor of ten/five higher compared to the value for UK. Consequently, the difference in 'collective E/y/1000 pop' for chest examinations between Germany and the UK is as high as a factor of 34. However, chest examinations contribute only 0.7%, 2.6 % and 5.2% to the collective E from all x-ray examinations in the UK, Switzerland and Germany, respectively.

Lumbar spine: Most striking is the high value for the mean effective dose per examination for Switzerland which is more than twice that for Germany and a factor of about 7 higher than the UK.

Pelvis/hip: Although the number of examinations is about twice as high for Germany compared to Switzerland, the collective effective dose for Switzerland peaks due to the high mean effective dose per examination being three to four times the values estimated for Germany/UK.

In the second category (radiography/fluoroscopy, including interventional; middle panels), the expected trends in frequency between the three countries are seen for four of the six exams, but for 'barium enemas' the UK frequency is six times that of Switzerland and over twice that of Germany, while for 'barium follows' it is about twice that of Switzerland (and about half that of Germany). The UK again has the lowest mean E per exam values for most examinations, particularly for barium meals and follows. The most striking peaks in 'collective E/y/1000 pop' are related to Germany, and are for IVU, cardiac angiography and PTCA.

IVU: The mean effective doses per exam are of similar magnitude for the three countries. However, there are big differences in the number of examinations, the number for Germany being three to five times the number for Switzerland/UK.

Cardiac angiography: The situation is the same as for IVU, the doses being similar and the examination frequency being about 4.5 times higher for Germany compared to Switzerland/UK.

PTCA: The examination frequency is similar for Germany and Switzerland being two to three times higher than for UK. The mean effective dose per examination for Germany is about twice that for Switzerland and the UK.

In the third category (CT, lower panels), Germany has the highest frequency for all CT examinations while the UK has the lowest for four CT exams and Switzerland for three (this may be a reflection of the fact that the Swiss survey was conducted 3 years earlier than the UK survey). The doses are fairly similar for 4 of the CT exams, but considerably higher for Germany for CT abdomen and trunk exams and higher for Switzerland for CT spine. The most prominent peak in collective effective dose is the one for abdomen CT in Germany, with two less pronounced peaks for CT of the head and of the chest.

CT abdomen: the peak in collective effective dose is caused by both a higher frequency as well as a higher mean effective dose per exam for Germany. Altogether this results in the 'collective E/y/1000 pop' being four to six times higher for Germany than for Switzerland or the UK. It is noteworthy that the 'collective E/y/1000 pop' due to abdomen CT in Germany is higher than the **total** 'collective E/y/1000 pop' due to **all** x-ray examinations in the UK.

CT head/chest: The higher collective effective dose for Germany is caused by a higher examination frequency.

9.2.2 Data on selected 'Top 20 Exams' for all ten countries

The following Figures (2-5) show the same frequency, mean dose and collective dose information as Figure 1, but for a restricted number of the 'Top 20 exams' and for all 10 DOSE DATAMED countries.

The countries are arranged in ascending order of per caput effective dose from all x-ray examinations (top down) and the calendar year in which the survey was performed is indicated on the left ordinate. Data are shown for a selection of the 'Top 20 exams' for which the mean effective dose exceeded 1 mSv in any country. Such plain film radiographic examinations are shown in Figure 2, radiography/fluoroscopy examinations in Figure 3, CT examinations in Figure 4 and angiography and interventional procedures in Figure 5. Below each figure is a Table which shows values of the maximum factor by which the countries are different, i.e. the factor between the country with the highest value and the country with the lowest value ("Max/Min"). These values are given for each examination with respect to frequency, mean effective dose per examination and 'collective E/y/1000 pop'.

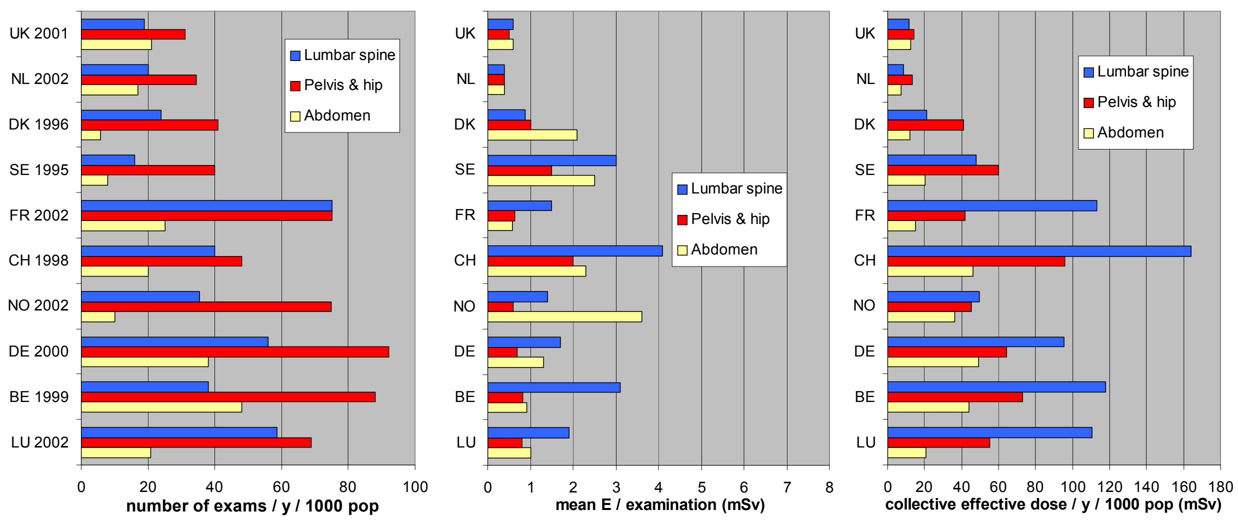


FIGURE 2 Frequency and dose data for three plain film radiographic exams in 10 countries

Exam	**Ratio between highest and lowest national value (max/min)**		
	Frequency	**Mean E / exam**	**Collective E/y/1000 pop**
Lumbar spine	5	10	19
Pelvis & hip	3	5	7
Abdomen	8	9	7

Figure 2 gives the results for examinations of the lumbar spine, pelvis/hip, and abdomen. The 'collective E/y/1000 pop' for lumbar spine examinations are higher than average for Switzerland, Belgium, France, Luxembourg, and Germany. For France, Luxembourg, and Germany this is caused by a higher than average frequency of lumbar spine exams. For Switzerland and Belgium this is due to the high mean effective dose per lumbar spine examination. For Sweden, the mean effective dose per lumbar spine examination is also higher than average, however the corresponding frequency is the lowest. The 'collective E/y/1000 pop' due to pelvis/hip examinations peaks for Switzerland, and is also higher than average for Belgium, Germany, Sweden, and Luxembourg. For Belgium, Germany, and Luxembourg this results from higher than average pelvis/hip examination frequencies, for Switzerland and Sweden, this is due to higher mean effective doses per pelvis/hip examination. For abdomen examinations, the mean collective effective dose per caput is higher than average for Germany, Switzerland, Belgium and Norway. This is caused by high abdomen examination frequencies in the case of Germany and Belgium, and by high mean effective doses per abdomen examination in the case of Switzerland and Norway. For Sweden and Denmark, there are also higher than average mean effective doses per abdomen examination, yet the respective frequencies are the lowest.

It is remarkable that the frequency per head of population of these well-established plain film radiographic examinations should vary by factors of between 3 and 8 in the ten countries. It is perhaps even more remarkable that the mean effective doses for these examinations should vary by factors of between 5 and 10 in the ten countries.

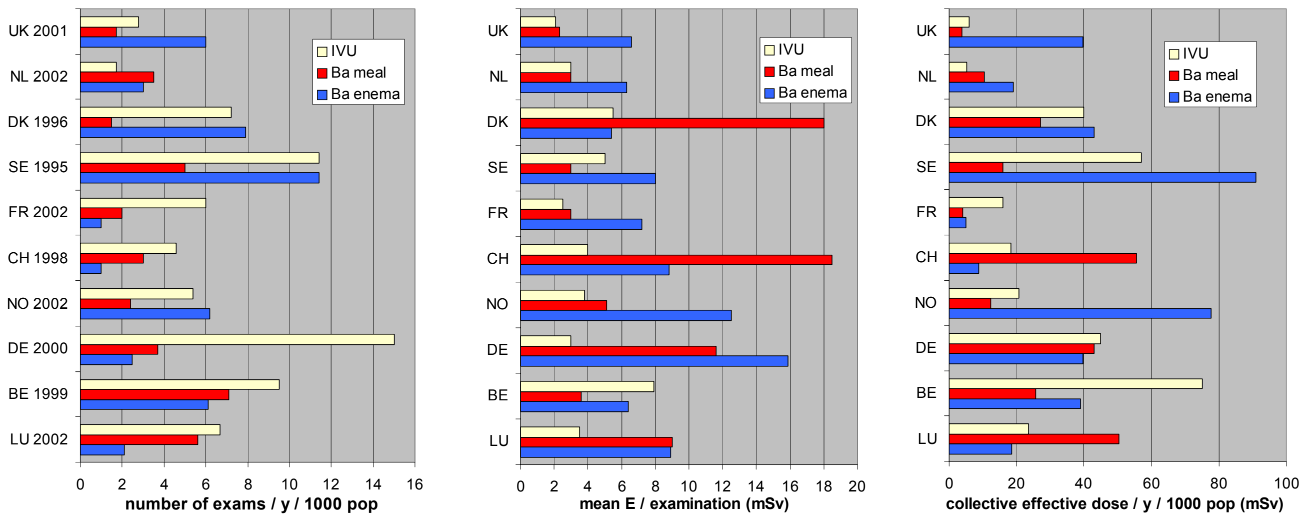


FIGURE 3 Frequency and dose data for three radiographic/fluoroscopic exams in 10 countries

Exam	Ratio between highest and lowest national value (max/min)		
	Frequency	Mean E / exam	Collective E/y/1000 pop
IVU	9	3	14
Ba meal	5	6	14
Ba enema	11	3	18

Figure 3 gives the results for IVU, Ba meal, and Ba enema examinations. For IVU examinations, the differences in 'collective E/y/1000 pop' are high, the factor between the country with the lowest value (Netherlands) and the highest value (Belgium) being 14. Along with Belgium, the 'collective E/y/1000 pop' from IVU examinations are more than average for Sweden, Germany, and Denmark. For Belgium and Sweden this is the result of a more than average IVU examination frequency as well as a high mean effective dose per IVU examination, for Germany this is due to an exceptionally high IVU examination frequency, and for Denmark this is caused by a more than average mean dose per examination. For Ba meal examinations, the 'collective E/y/1000 pop' values are highest for Switzerland, Luxembourg, and Germany. For Germany and Switzerland, this is caused by a high mean dose per Ba meal examination, for Luxembourg, this is due to both, a higher than average mean dose per Ba meal examination and a higher frequency. The mean dose per Ba meal examination is also very high for Denmark, however, the corresponding frequency is the lowest. For Ba enema examinations, there are also large differences in 'collective E/y/1000 pop' between the countries, the highest values being those for Sweden and Norway, the lowest being those for France and Switzerland. The per caput number of Ba enema examinations is especially high for Sweden, Denmark, Norway, Belgium, and UK. The mean effective dose per Ba enema examination is notably high for Germany and Norway.

The large variation in the frequency per head of population for IVUs and barium meals and enemas between the ten countries (factors of 5-11) is remarkable, but could be partly due to differences in the rate of adoption of alternative imaging techniques involving ultrasound, endoscopy or CT in the different countries surveyed at different times.

The mean effective doses for IVUs and barium enemas are within a factor of 3 in the ten countries, but vary by up to a factor of 6 for barium meals due to exceptionally high doses in Denmark and Switzerland.

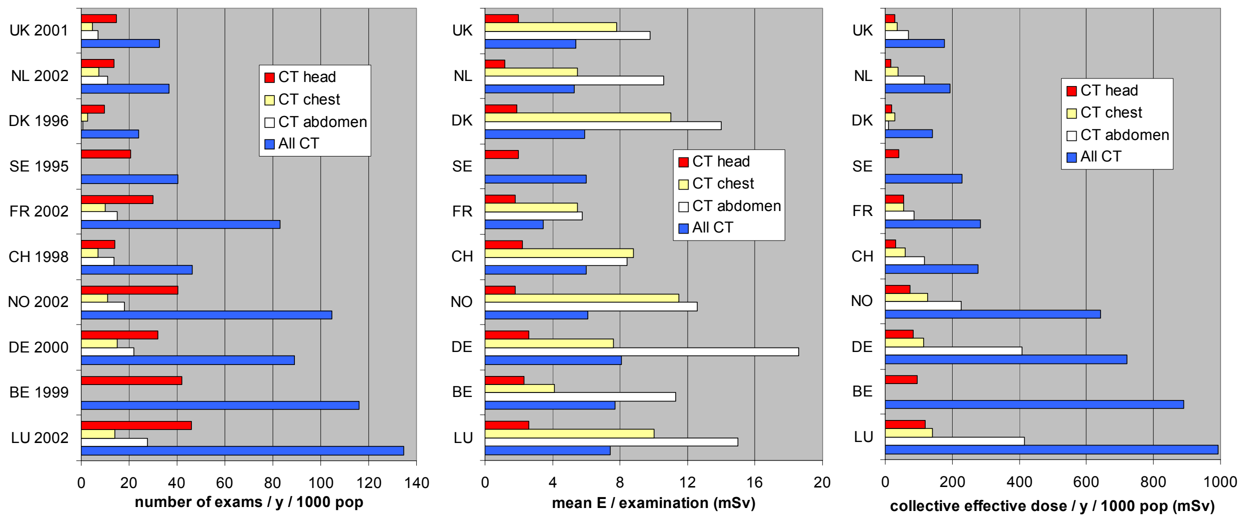


FIGURE 4 Frequency and dose data for three CT examinations and all CT in 10 countries

Exam	Ratio between highest and lowest national value (max/min)		
	Frequency	**Mean E / exam**	**Collective E/y/1000 pop**
CT head	5	2	7
CT chest	6	3	5
CT abdomen	45	3	47
All CT	6	2	7

Figure 4 gives the results for CT examinations of the head, chest, abdomen, and for all CT examinations. The values of the mean E per exam for **all** CT examinations are of the same order of magnitude in each country, except for France where it is about half the average value for all the other countries. The differences in 'collective E/y/1000 pop' between countries is consequently mainly due to the different CT examination frequencies. Roughly the same is true for CT examinations of the head. There are larger deviations in the mean E per exam for CT chest and CT abdomen. However, the differences in 'collective E/y/1000 pop' for CT chest and CT abdomen arise for the most part from the differences in frequencies. Because of the general trend of increasing frequency of CT examinations over the years, it is important to take into account the calendar year in which the surveys were performed, especially for Denmark and Sweden. Excluding Denmark and Sweden, the max/min ratios would be considerably lower (e.g. in the case of CT examinations of the abdomen the factors would be 4 instead of 45 for frequency and 6 instead of 47 for 'collective E/y/1000 pop'.

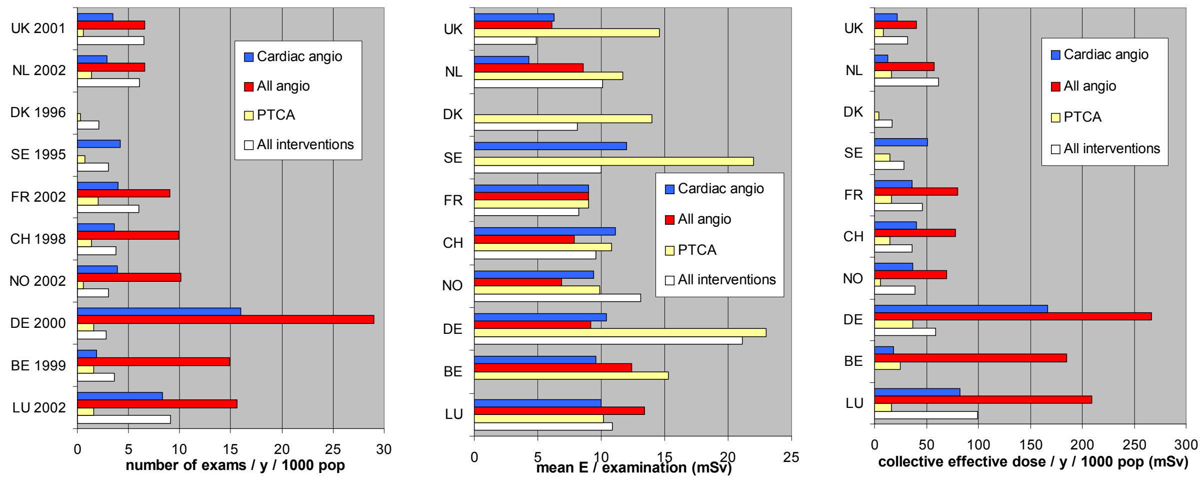


FIGURE 5 Frequency and dose data for three angiography or interventional procedures and all interventional procedures in 10 countries

Exam	**Ratio between highest and lowest national value (max/min)**		
	Frequency	**Mean E / exam**	**Collective E/y/1000 pop**
Cardiac angio	8	3	13
All angio	4	2	5
PTCA	6	3	8
All intervent.s	4	3	6

Figure 5 gives the results for cardiac angiographies, all angiographies, PTCA, and all interventions. The 'collective E/y/1000 pop' for cardiac angiography is above-average for Germany and Luxembourg. For Germany, this is clearly due to a strikingly high per caput number of cardiac angiographies. For Luxembourg, both, frequency and mean effective dose for cardiac angiography are higher than average. The 'collective E/y/1000 pop' for all angiography is higher than average for Germany, Luxembourg, and Belgium. For Germany, again, the reason for this is a remarkably high frequency of angiographies. For Luxembourg and Belgium, the frequency as well as the mean dose for all angiographies are above-average. The 'collective E/y/1000 pop' for PTCA is far above-average for Germany and Belgium, and slightly above-average for Luxembourg, Netherlands, and France. For Germany and Belgium this is caused by higher than average values for both, PTCA frequency and mean effective dose per examination. For Luxembourg, Netherlands, and France this is due to higher than average PTCA frequencies. Finally, the 'collective E/y/1000 pop' for all interventions is highest for Luxembourg and above-average also for Netherlands and Germany. In the case of Luxembourg, the frequency for all interventions is about twice the average value, for Germany the mean effective dose per examination is about twice the average, and for Netherlands, the frequency is higher than average by about 40%.

9.2.3 *Major differences in frequency of Top 20 Exams between countries*

The frequencies of the Top 20 exams (from Tables A3.1-A3.10) in the ten countries are brought together in the Table below. The year(s) in which the frequency data were obtained are indicated below the country symbol at the top of each column. For each type of examination the maximum frequency is shown in **red** and the minimum in **blue**. The ratio of the maximum to the minimum frequency is shown in the last column of the Table. The countries are arranged from left to right in descending order of per caput effective dose from all x-ray examinations.

Exam type	**Number of exams/year /1000 population**										
	LU 2002	**BE** 96-02	**DE** 2000	**NO** 2002	**CH** 1998	**FR** 99-02	**SE** 1995	**DK** 1995	**NL** 2002	**UK** 2001	**Max / Min**
1. Chest/thorax	174	**313**	273	161	213	**91**	135	129	137	141	3.4
2. Cervical spine	29.8	34	**64**	20.3	22	29	-	**11**	11.2	14	5.8
3. Thoracic spine	18.4	19	**29**	8.8	11	24	-	12	7.8	**5**	5.8
4. Lumbar spine	58.5	38	56	35.3	40	**75**	**16**	24	20.0	19	4.7
5. Mammography	54.9	**99**	41	76.7	31	91	85	**17**	59.0	27	5.8
6. Abdomen	20.7	**48**	38	10.1	20	25	8	**5.7**	17.0	21	8.4
7. Pelvis & hip	68.9	88	**92**	74.9	48	75	40	41	34.3	**31**	3.0
8. Ba meal	5.6	**7.1**	3.7	2.4	3	2	5	**1.5**	3.5	1.7	4.7
9. Ba enema	2.1	6.1	2.5	6.2	**1**	**1**	**11.4**	7.9	3.0	6	11
10. Ba follow	0.5	**1.8**	1.2	**1.8**	**0.37**	1	-	1.6	0.7	0.7	4.9
11. IVU	6.7	9.5	**15**	5.4	4.59	6	11.4	7.2	**1.7**	2.8	8.8
12. Cardiac angio.	8.3	**1.9**	**16**	3.9	3.63	4	4.2	-	2.9	3.5	8.4
All Angiography	***15.6***	***14.9***	***29***	***10.1***	***9.87***	***9***	**-**	-	***6.6***	***6.6***	***4.4***
13. CT head	**46.1**	42	32	40.4	14	30	20.5	**9.8**	13.7	14.6	4.7
14. CT neck	**8.0**	-	5	2.3	3.1	1	-	**0.31**	-	0.6	26
15. CT chest	14.0	-	**15**	10.9	6.93	10	-	**2.7**	7.2	4.6	5.6
16. CT spine	**23.0**	-	10	16.9	5.83	22	-	2.0	2.6	**1.4**	16
17. CT abdomen	**27.6**	-	22	17.9	13.8	15	-	**0.62**	10.9	7	45
18. CT pelvis	-	-	4	**11.4**	1.03		-	**0.17**	0.9	3.3	67
19. CT trunk	3	-	1	0	–	-	-	4.7	-	**0.4**	12
All CT	***135***	***116***	***89***	***105***	***46.3***	***83***	***40.4***	***24***	***36.6***	***32.7***	***5.6***
20. PTCA	1.6	1.6	1.6	0.6	1.37	**2**	0.7	**0.31**	1.4	0.6	6.5
All Interventional.	***9.1***	***3.6***	***2.8***	***3***	***3.77***	***6***	***3***	***2.1***	***6.1***	***6.5***	***4.3***

For most of the Top 20 Exams the maximum annual frequencies per head of population occur in Luxembourg, Belgium or Germany – the three highest collective dose countries.

The minimum annual frequencies per head of population occur in Denmark, the Netherlands or the UK – the three lowest collective dose countries. The low Danish frequencies (particularly for CT examinations) could be due to the early year of their survey (1995) but this is not so for the Dutch and UK surveys that are more recent (2002 and 2001, respectively).

Max/Min frequency values (last column in above Table) range over factors of 3-11 for non-CT examinations and reach as high as a factor of 67 for CT examinations due to the low numbers of CT examinations performed in the Danish survey in 1995 compared to the later surveys in other countries.

9.2.4 Major differences in mean effective dose for Top 20 Exams between countries

The mean effective dose values estimated for the Top 20 exams (from Tables A3.1-A3.10) in the ten countries are brought together in the Table below. The year(s) in which the dose data were obtained are indicated below the country symbol at the top of each column. For each type of examination the maximum dose is shown in **red** and the minimum in **blue**. The ratio of the maximum to the minimum dose is shown in the last column of the Table. The countries are arranged from left to right in descending order of per caput effective dose from all x-ray examinations.

Exam type	**Mean E per examination (mSv)**										
	LU -	**BE** 00-05	**DE** 92-05	**NO** 85-95	**CH** 1998	**FR** 01-03	**SE** 1995	**DK** 1995	**NL** 2002	**UK** 90-01	**Max** **Min**
1. Chest/thorax	0.2	0.1	**0.3**	0.1	0.12	0.05	0.15	0.11	0.04	**0.02**	15
2. Cervical spine	0.2	0.3	0.3	0.2	**1.1**	0.07	-	0.2	**0.02**	0.07	55
3. Thoracic spine	0.7	1.4	0.5	0.7	**3.5**	0.8	-	0.6	**0.3**	0.6	12
4. Lumbar spine	1.9	3.1	1.7	1.4	**4.1**	1.5	3.0	0.9	**0.4**	0.6	10
5. Mammography	0.5	0.2	**0.6**	**0.1**	0.2	0.4	0.3	0.5	0.2	0.3	6
6. Abdomen	1.0	0.9	1.3	**3.6**	2.3	0.6	2.5	2.1	**0.4**	0.6	9
7. Pelvis & hip	0.8	0.8	0.7	0.6	2.0	0.6	**1.5**	1.0	**0.4**	0.5	3.8
8. Ba meal	9.0	3.6	11.6	5.1	**18.5**	3.0	3.0	18.0	3.0	**2.3**	8
9. Ba enema	8.9	6.4	**15.9**	12.5	8.8	7.2	8.0	**5.4**	6.3	6.6	2.9
10. Ba follow	8.8	10.0	15.5	**2.2**	**42.3**	3.0	-	3.7	5.5	3.3	19
11. IVU	3.5	**7.9**	3.0	3.8	4.0	2.5	5.0	5.5	3.0	**2.1**	3.8
12. Cardiac angio.	10	9.6	10.4	9.4	11.1	9.0	**12.0**	-	**4.3**	6.3	2.8
All Angiography	***13.4***	***12.4***	***9.2***	***6.9***	***7.9***	***9.0***	-	-	***8.6***	***6.1***	***2.2***
13. CT head	**2.6**	2.3	**2.6**	1.8	2.2	1.8*	2.0	1.9	**1.2**	2.0	2.2
14. CT neck	2.5	-	2.5	**3.4**	3.1	2.5*	-	**1.3**	-	2.4	2.6
15. CT chest	10.0	**4.1**	7.6	**11.5**	8.8	5.5*	-	11.0	5.5	7.8	2.8
16. CT spine	9.0	-	**2.9**	4.3	**9.1**	4.0*	-	5.7	3.1	4.2	3.1
17. CT abdomen	15.0	11.3	**18.6**	12.6	8.4	**5.8** *	-	14.0	10.6	9.8	3.2
18. CT pelvis	-	-	**10.6**	9.3	**7.0**	-	-	8.3	7.4	9.8	1.5
19. CT trunk	**7.9**	-	**24.4**	-	-	-	10	15.0	-	10.4	3.1
All CT	***7.4***	***7.7***	***8.1***	***6.1***	***6.0***	3.5*	***6.0***	***5.9***	***5.3***	***5.4***	***2.3***
20. PTCA	10.2	15.3	**23.0**	9.9	10.8	**9.0**	22.0	14.0	11.7	14.6	2.6
All Interventional	***10.9***	-	***21.1***	***13.1***	***9.6***	***8.3***	***10***	***8.1***	***10.1***	***4.9***	***4.3***

* Mean E values for only one CT sequence

Doses for Germany tend to be higher than for all other countries for most examinations, particularly CT. CT doses for Luxembourg and Belgium are also relatively high, but no patient doses were specifically measured in Luxembourg and estimates for the Grand Duchy were based on recently published studies in Germany and Switzerland. The mean effective dose for all CT examinations ranges from 3.5 mSv for France to 8.1 mSv for Germany (a factor of 2.3). The relatively low French CT doses could be explained by the fact that they are based on patient dose surveys that were conducted for establishing diagnostic reference levels (DLRs) in France, which are related to only one CT scan sequence per examination [Beauvais-March et al, 2004]. An analysis of the scan protocols actually used in the CT examinations was missing from this French survey, so that the dose-length product (DLP) values estimated for a single sequence (and the effective dose values calculated from them) generally underestimated the dose for actual CT examinations by a factor of 1.5 to 2.

Max/Min values of mean E (last column of above Table) reach factors of 10 or over for some radiographic and fluoroscopic examinations. This is either the result of exceptionally low doses in the Netherlands and the UK (for chest and cervical spine radiographs) and/or exceptionally high Swiss doses for radiographs of the spine, 'barium meals' and 'barium follows'. The high Swiss dose for barium meals is substantiated by their recently published DRL for this examination (DAP = 100 Gy cm^2) [Trueb, 2006] which is nearly 8 times the current value for the UK of 13 Gy cm^2 [Hart et al, 2002]. On the other hand the recently published DRL for barium enemas in Switzerland (DAP = 150 Gy cm^2) is nearly 5 times the current UK value (31 Gy cm^2) and yet the mean effective dose (8.8 mSv) is only 33% higher than the UK value (6.6 mSv) in the above Table. Cervical, thoracic and lumbar spine radiographs also appear to involve exceptionally high patient doses in Switzerland but it should be remembered that the effective doses were calculated in 1998 from the protocols and technical parameters of the examinations as agreed upon by a panel of experts (radiologists, generalists, radiographers, etc.) representative of the whole country. For example, radiographies of the spine (cervical, thoracic, and lumbar) were established considering two projections in each examination (AP and Lateral). Also the number of radiographs and time of fluoroscopy for the barium studies of the digestive tract were those commonly used in Switzerland nearly 10 years ago and practice has probably changed significantly since then. The Netherlands have the lowest doses for nearly all radiographic examinations and their doses are based on surveys conducted in 2002, the most recent of all DOSE DATAMED countries.

The mean effective doses for all angiography examinations range over a factor of about 2 from 6.1 mSv for the UK to 12.4 mSv and 13.4 mSv for Belgium and Luxembourg respectively. The mean effective doses for all interventional procedures range over a factor of 4.3 from 4.9 mSv for the UK to 21 mSv for Germany.

9.2.5 Current trends in frequencies of Top 20 Exams

A rough indication of the current trends in frequency for each of the top 20 examinations in each country, based on the experience of the representatives from each country in the DOSE DATAMED project, are shown in the last column of Tables A3.1–A3.10. A plus sign indicates increasing frequency, a minus sign indicates a decrease, while a zero indicates no change. The majority of countries indicated that CT was increasing, and that barium meals, barium enemas and IVUs were decreasing. Plain film radiography of the chest is thought to be decreasing in 5 countries and increasing in none, in contrast to mammography which is increasing in 5 countries and decreasing in none. The other top 20 examinations do not show such a clear consensus. Half of the countries indicated that PTCAs and other interventional procedures were increasing, and it seems likely that this is a general trend since most other countries admitted to having insufficient data to estimate the trend. Surprisingly, while cardiac angiography shows an upward trend in four countries and a downward trend in two, angiography as a whole only has an upward trend in one country and a downward trend in four countries.

10. Discussion

It is clear from the above results that there are considerable differences in the estimated total average annual effective doses per head of population from all x-ray examinations in the ten countries studied. These are a result of differences in both the estimated numbers of examinations performed per head of population and in the estimated mean effective doses per examination. There are considerable uncertainties in the estimated frequency and dose values for each country and an attempt to quantify these uncertainties, at least for three countries, is made in Appendix 2 and summarised at the end of the respective methods sections. Although the uncertainties in the frequency estimates for some of the examinations making major contributions to the collective dose can be large (5%-50%), each one will have only a small impact on the accuracy of the total frequency estimate for all examinations together, which was found to lie between ±1.5% and ±6% (at the 95% confidence level) for the three countries studied. Estimates of the mean effective dose for these examinations generally have larger uncertainties than the frequency estimates (15% - a factor of 2) but again, their impact on the estimate of the total collective doses from all examinations together is small, resulting in overall uncertainties on the total collective dose estimates of about ±7%, ±12% and ±20% (at the 95% confidence level) for the three countries studied.

It would therefore appear to be reasonable to compare the overall results for each country which are described in section 9.1 on the understanding that some of them could be in error by up to ±20%. No significant differences were seen between the population dose surveys in the ten countries regarding their coverage of all types of healthcare provider carrying out x-ray imaging, so there should be no additional systematic error in any country's collective dose estimate due to the omission of an important sector of their radiology services.

With this potential level of uncertainty the ten countries can still be sensibly divided into 3 groups according to the total medical x-ray examination frequency. In the 1st group, Germany, Belgium and Luxembourg perform about 1000 examinations per 1000 population; in the 2nd group, France, Switzerland and Norway perform about 750 examinations per 1000 population; and in the 3rd group Sweden, Denmark, the Netherlands and the United Kingdom perform about 500 examinations per 1000 population. The differences of 25% and 50% in the total examination frequency between these three groups are significant and are thought to be primarily due to differences in the healthcare systems operating in each country, as discussed in section 5.

The most significant difference in the health care systems between the ten countries would appear to be the numbers of radiologists and other doctors per head of population who are involved in diagnostic radiology. For the countries in the 1st group (Germany, Belgium and Luxembourg) it is estimated that between 300 and 380 radiologists and other doctors per million population, are involved in the justification, performance and/or clinical evaluation of x-ray examinations, with the vast majority of the examinations being self-referred by a non-radiologist doctor to him/herself. In contrast, the two countries in the 3rd group for which this data is available (UK and Sweden) are thought to have less than half the number of radiologists and other doctors per head of population involved in diagnostic radiology, and most of the examinations are radiologist-referrals. Moreover, the percentage of radiologists and doctors who are paid per examination rather than being on a fixed salary is much higher in Germany, Belgium and Luxembourg than in any other country. These potential financial incentives for providing radiology services together with over double the number of doctors available for providing them, are probably the major factors that are responsible for twice the frequency of x-ray examinations being conducted in the 1st group of countries compared to the 3rd group.

The number of radiographers per head of population appears to show no distinct trend with examination frequency, but most countries have similar provision (about 300 per million population) with only Switzerland and Norway (both in the 2nd group) having significantly more with 684 and 510 per million, respectively.

Although there appears to be no clear correlation between the percentage of Gross Domestic Product (GDP) devoted to healthcare and the frequency of x-ray examinations, the level of resources in terms of x-ray imaging equipment does vary between countries and shows some relation to examination frequency. For example, the provision of general x-rays sets per head of population is on average about 50% higher in the 1st group of countries compared to the 3rd group and the provision of CT scanners is about twice as high.

In all 4 of the countries in the 3rd group, only 10% or less of x-ray examinations are performed in private practice. Consequently, in the countries with the lowest examination frequencies, radiology practice is mainly state-run and it also happens to be by a centralised rather than a federal government. The implementation of legislation and recommendations regarding the justification and optimisation medical exposures (e.g. in compliance with the EC Medical Exposure Directive) may be easier in countries with such centralised health care systems. There is some evidence for this in that the European Commission referral guidelines (EC, 2001) suggest that x-ray examinations of the lumbar spine should not be carried out routinely in cases of back pain, and lumbar spine examinations are seen to be far less common in the UK, Netherlands, Denmark, and Sweden, than in the other six countries (see Figure 2).

The total frequency of all types of medical and dental x-ray examination has been fairly stable or has only shown a gradual increase (1-2% per year) over the past ten years in most countries. However, some types of examination such as CT have been rapidly increasing, while others like barium meals, enemas and IVUs have been in slow decline. In particular, the frequency of CT examinations and their contribution to the collective dose will be very dependant on the year in which the population dose was assessed. This could be one reason why Sweden and Denmark, whose latest frequency surveys were conducted in the mid 1990s, appear in group 3.

Although the uncertainties in the estimated frequencies for some individual types of examination can be large in some countries, they are unlikely to mask real differences between countries when these are larger than a factor of 3 or 4. The Tables under Figures 2-5 and the last columns of the Tables in sections *9.2.3* and *9.2.4* indicate that differences in the frequency of specific types of examination between countries can often be much larger than a factor of 3 or 4. The most prominent differences are described in the previous sections. In summary, it is apparent that the maximum frequencies for most of the Top 20 Exams occur in the group 1 countries (Luxembourg, Belgium or Germany) and that they are higher than those in the countries with the lowest frequencies by factors of between 3 and 67 if the earlier surveys in Denmark and Sweden are included, but by factors of between 3 and 16 if they are not.

As well as the estimated frequency of examinations, the other main factor influencing the collective dose is the estimated mean effective dose per examination. Estimates of the mean effective dose generally have larger uncertainties than the frequency estimates, as discussed in Appendix 2, and are likely to range from 15% - 60% for each of the Top 20 Exams, depending mostly on the number of patient dose measurements made and how representative they are of national practice. However, estimated mean effective doses for the Top 20 Exams are seen to range over factors of 1.5 to 55 between the ten countries (see Table in *9.2.4*), so the larger differences (say > a factor of 3) are unlikely to be due solely to measurement uncertainties.

The most prominent differences in the estimated national mean effective doses for the Top 20 Exams are described in section 9.2. Doses for Germany tend to be higher than for all other countries for most examinations, particularly CT, and doses for Luxembourg and Belgium are generally not far behind. Doses tend to be the lowest in the Netherlands and the UK for most examinations except CT. France has the lowest dose for 'All CT' examinations, being over a factor of 2 lower than Germany's, but this may be due to an underestimation of the number of CT sequences actually used in clinical practice in France. Since CT examinations make a major contribution to the total collective dose from all x-ray examinations, this 'underestimation' could be responsible for the relatively low total per caput E value for France in relation to its total x-ray examination frequency.

One reason for the relatively low doses for most examinations in the UK is the long history of patient dose surveys and the establishment and regular updating of national reference doses for common x-ray examinations that has taken place since the early 1990s. UK reference doses for radiographic and fluoroscopic examinations have more than halved between 1990 and 2005 and those for CT examinations have dropped by 10-50% between 1990 and 2003. National guidance on the establishment and use of diagnostic reference levels (DRLs) at the local hospital level has been available in the UK for a number of years, whereas most other European countries are only at the initial stages of implementing DRLs.

However, it is difficult to determine the reasons for differences in national mean dose values of a factor of 15 or over for some of the radiographic and fluoroscopic examinations (see Table in *9.2.4*). These large differences are either the result of exceptionally low doses in the Netherlands and the UK for chest and cervical spine radiographs, and/or the exceptionally high German dose for chest radiography and the exceptionally high Swiss doses for barium meals and barium follows.

11. Conclusions

Large differences in the population dose from all medical and dental x-ray examinations have been observed between some of the ten European countries studied in this project. For example, a difference of about a factor of four in the mean per caput effective dose has been seen between the three highest countries and the three lowest countries. These differences are thought to be real (i.e. much larger than the uncertainties) and primarily due to the different healthcare systems operating in each country. Generally speaking, the different healthcare systems result in a much higher provision of radiology services (both medical staff and imaging equipment), higher financial incentives for radiology and less opportunity for central government control, in the countries with high population doses compared to those with low doses.

However, the assessment of the population dose from medical and dental x-rays is not a simple task and great care has to be taken to obtain reliable results that accurately reflect the full extent of radiology practice in a country and its impact on population exposure. Harmonised guidance on how to conduct population dose surveys for medical exposures to improve the comparability of results from European countries would be extremely useful. Such guidance is provided in DD Report 2.

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APPENDIX 1

BRIEF ACCOUNTS OF RECENT NATIONAL SURVEYS OF POPULATION DOSE FROM MEDICAL X-RAYS IN TEN EUROPEAN COUNTRIES

1.	UK	1997-2001
2.	Switzerland	1998
3.	Netherlands	2002
4.	Germany	1996-2002
5.	France	1999-2002
6.	Norway	2002
7.	Sweden	1995
8.	Luxembourg	2002
9.	Belgium	1996-2005
10.	Denmark	1995

1. UK POPULATION DOSE FROM MEDICAL X-RAYS 1997-2001

David Hart

Survey dates

The latest detailed assessment[1] was based on a survey of the frequency of x-ray examinations carried out in the financial year 1997/98 and on patient dose measurements collected by NRPB throughout the 1990s.

This thorough estimate was roughly updated to 2001/02[2], using radiology workload statistics collected by the Department of Health and revised patient doses for some of the x-ray examinations.

METHODS

Frequency of examinations in NHS hospitals in 1997/98

The NRPB x-ray examination frequency survey[3] was based on data gathered from two geographically separate English National Health Service regions (Trent and South Thames) in the financial year 1997/98. A sample of 38 out of the 65 NHS trusts in these regions sent details on the number of medical x-ray examinations of different types that they had performed in the year, as recorded in their computerised radiology information systems (RIS). Whereas data were sent from 58% of the trusts in the two regions, the sample was biased towards larger trusts so that 68% of all x-ray examinations in the two regions were covered, amounting to 16% of all x-ray examinations in England. Despite an occasionally confusing mixture of terminology adopted by the trusts for describing the different types of x-ray examination, 99% of the data was finally allocated to 150 distinct and identifiable types of examination.

The survey data was extrapolated to the whole of the English NHS using annual statistics on the total numbers of all types of x-ray examination conducted in each trust that were collected by the Department of Health (known as KH12 returns). Similar KH12 returns were available from Wales and Northern Ireland and were used to estimate x-ray examination frequencies in NHS hospitals in these two countries. Identical levels of radiology provision (450 x-ray examinations per 1000 head of population) were found to exist in England, Wales and Northern Ireland. No KH12 returns were available from Scotland, so the same level of 450 exams per 1000 population was assumed to apply to Scotland to extend the analysis to all NHS hospitals in the UK.

Frequency of x-ray examinations outside NHS hospitals in 1997/98

Reliable information was obtained from the Dental Practice Board on the annual numbers of dental x-ray examinations conducted in England and Wales by dentists operating within the NHS. The same rates of NHS dental x-ray practice were assumed to apply in Scotland and Northern Ireland. An additional 25% of x-ray examinations were assumed to be performed in private dental practice, based on a rough estimate from the British Dental Association. A fairly reliable estimate of the numbers of mammography screening x-ray examinations conducted in 1997/98 was based on information for the previous year from the NHS Breast Screening Programme. 170 independent (private) hospitals in the UK were known to have x-ray facilities in 1997/98 and a rough estimate of the number of examinations they performed was based on comparisons with NHS hospitals of similar size. Sufficient information was also available to make approximate estimates of the numbers and type of x-ray examinations conducted in Ministry of Defence hospitals and medical units, prisons, and chiropractic clinics.

These numbers were added to the NHS numbers for the corresponding types of examination, to provide the total numbers for each of the 150 types of examination, performed both inside and outside the NHS.

Typical effective doses for examinations in 1997/98

A typical effective dose was attributed to each one of the 150 distinct and identifiable types of x-ray examination found in the frequency survey. To do this, estimates of the mean effective dose for each examination were obtained from a number of sources, the predominant one being the National Patient Dose Database (NPDD) maintained by NRPB.

Patient doses, measured according to a National Protocol[4], are sent to NRPB by medical physicists from hospitals throughout the UK. Doses are recorded in the NPDD as entrance surface dose (ESD) or dose–area product (DAP) values for individual radiographs, and DAP values for complete examinations. The 'typical' dose for a specific radiograph or examination was taken to be the mean of the doses recorded in the NPDD over the whole of the 1990s. Data for the whole decade were used in order to get a sufficient sample size, even for the less common examinations. The mean dose for each examination was derived by firstly calculating the mean dose for the sample of patients measured in each radiology room and then taking the mean of these room mean values. In this way equal weight was given to each radiology room in the NPDD. The latest review of the NPDD for the period 1996-2000 was presented in NRPB-W14[5].

NRPB-R262[6] contains generalised conversion coefficients, for estimating effective dose from ESD and DAP measurements, assuming that the x-ray spectra (tube voltage and total filtration) used are close to the average. For some radiographs and examinations, a conversion coefficient was not directly available from NRPB-R262. Suitable conversion coefficients were estimated for five additional examinations (including 'extremities') and four additional radiographs, by comparison with existing conversion coefficients for similar examinations. A typical effective dose estimate was thus obtained from the National Patient Dose Database for 90 examinations out of the 150.

Published surveys provided dose estimates for 25 further examinations that were not adequately covered in the NPDD. These included CT examinations, the doses for which were obtained from the NRPB survey completed in 1991[7] and a Welsh survey performed in 1994[8]. NRPB-R250[9] was used to convert the measured CT doses into effective doses. For the remaining 35 examinations an estimate of the effective dose was made by comparison with similar examinations for which the effective dose had already been estimated.

RESULTS

A total of 41.5 million medical and dental x-ray examinations were conducted in the UK in 1997/98, that is 700 examinations per year per thousand head of population. If dental examinations are excluded, then 28.5 million medical x-ray examinations were performed, that is 480 examinations per year per thousand head of population.

The total annual collective dose from all x-ray examinations in the UK was 19,300 man Sv. With a UK population of 59 million in 1997, this results in an annual per caput effective dose of 0.33 mSv. 40% of this population dose was due to CT, 10% to angiography, 6% to interventional procedures, and 44% to conventional examinations (including dental).
Figure 1 shows the 15 examinations making the biggest contribution to collective dose. The number in brackets after the examination name is the typical effective dose.

Uncertainties in the collective dose estimate

The uncertainty on the population dose was calculated to be about 9%, at the 95% confidence level. This was calculated by combining the uncertainties in the frequencies and the effective dose for each of the 150 types of examination. The uncertainties on the frequencies were given in the frequency survey[3] and were typically in the range 2% to 30%. The uncertainties on the effective dose were derived from twice the standard error on the mean for the series of dose measurements for each examination that were available to us (mainly in the NPDD). For those examinations with either very few or no dose measurements, the uncertainty on effective dose was put at 100% and 200% respectively. Less than 10% of the collective dose was due to examinations falling into these last two uncertain categories. The overall uncertainty was calculated from the square root of the sum of the squares of the uncertainties being combined. This formula was applied twice, once to calculate the uncertainty on the collective dose for each examination (combining the uncertainties on frequency and effective dose) and once to calculate the uncertainty on the total collective dose (combining the uncertainties on the collective dose for each examination).

Update to 2001/02

The above population dose estimate for the financial year 1997/98 was updated to 2001/02 in an article in the European Journal of Radiology[2]. Examination frequencies were updated using the KH12 returns for the two periods collected by the English Department of Health. CT examinations had increased in frequency by 39% from 1997/98 to 2001/02. Interventional procedures increased by 55%. Conventional radiography and fluoroscopy increased by 1%. Angiography was assumed to have continued to grow at 6% per annum. Allowance was also made for changes in doses for some common radiographic and fluoroscopic examinations for which the latest review of the NPDD[5] found a dose reduction of between 7% and 15%**.** The annual collective effective dose was revised to 22,700 man Sv and the per caput effective dose to 0.38 mSv.

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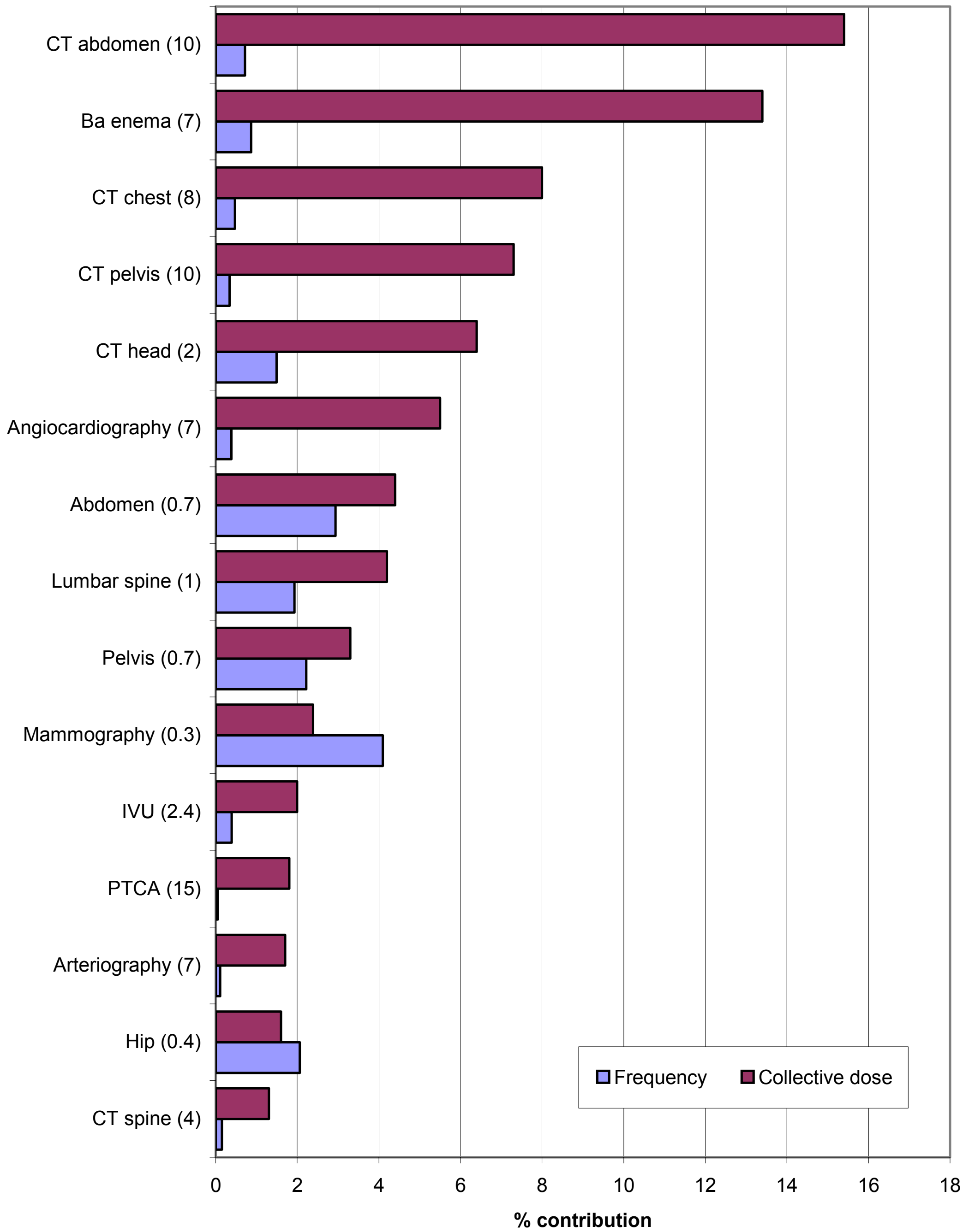
Figure 1: Contribution to UK collective dose and frequency from the 15 medical and dental x-ray examinations making the biggest contributions to collective dose



The number in brackets after the examination name is the typical effective dose in mSv.

2. SWISS POPULATION DOSE FROM MEDICAL X-RAYS 1998

Abbas Aroua

1. Introduction

Switzerland has a long tradition in this field going back over forty years (1-4). The last Swiss survey on medical exposure was undertaken in 1992, but no evaluation of the collective dose was made. Since then, several factors associated with demographic evolution, with changing indications prescription for examinations and with the techniques used, have altered the average dose to the population. A new evaluation of the latter quantity was therefore useful.

This survey falls within the same framework as earlier ones and its main objectives are: (a) to determine the radiation doses delivered in Switzerland by the various radiological examinations (diagnostic and interventional radiology), (b) to determine the frequencies of examinations according to patient age and gender, (c) to infer the global impact of diagnostic and interventional radiology on the Swiss population, (d) to study the diversity of medical practices involving the use of radiological examinations, (e) to formulate recommendations in order to reduce the doses if need be.

The survey has been carried out under the aegis of the Office fédéral de la santé publique by: the Institut universitaire de radiophysique appliquée (IRA – University institute of applied radiation physics) at Lausanne, which is responsible for the whole project and its coordination. The IRA also covers dosimetry-related matters and the final determination of the population impact indicators, and the Institut universitaire de médecine sociale et préventive (IUMSP – University institute of social and preventive medicine) at Lausanne, which provides expertise on the survey on the frequency of radiodiagnostic examinations and on survey consolidation methods. The Radiation physics institute of Isle hospital at Berne and the Department of diagnostic and interventional radiology of the Centre hospitalier universitaire vaudois (CHUV – University hospital of Vaud) at Lausanne both provided the expertise on several aspects: definition of examinations, working-out typical values for technical parameters, processing the data gathered in earlier surveys, etc. Moreover, the survey was supervised closely by a support group led by the Office fédéral de la santé publique and made up of the representatives of the main Swiss medical societies. The support group provided: (a) expertise on the methodology of the survey, (b) assistance to gather the data from physicians, (c) expertise to analyse the results and draw the conclusions, and (d) support for the publication of the results and recommendations.

2. Material and Methods

The survey's approach consists in determining the frequencies of the different types of examinations, on the one hand, and in finding out the dose delivered to the patient for each type of examination. The collective impact of radiodiagnostics is evaluated by convoluting these two data using appropriate risk models. The main outlines of the survey are given in Figure 1.

Concerning the dosimetric study, the basic quantities considered are the dosimetric indices obtained from the parameters of the examinations on the basis of dosimetric models. These models require a precise characterisation of each examination. The characterisation is first performed on the basis of the data gathered at the CHUV; it is then checked using a referee for each specialty and validated by a survey covering a sample of surgeries and several hospitals. The dose indices (ESD: entrance surface dose, KAP: kerma-area product, CTDI: CT dose index) are converted into doses to organs and effective doses using conversion factors taken from the literature and adapted to particular situations. The survey on the frequencies of examinations, which covers a larger sample, provides data on the frequency distribution of the various types of examinations according to patient age and gender. It enables the inference of their distributions by specialty, by type of healthcare provider and by geographical area. Seasonal variations are studied using monthly statistics provided by a sample of surgeries and hospitals. Finally, both the individual radiological impact and the collective impact of radiodiagnostics are evaluated using appropriate models built from our current understanding of the subject.

257 types of examinations were considered in order to obtain the finest definition. These types covered several broad categories: radiography (54 types), radiography and fluoroscopy (33 types), angiography (35 types), interventional radiology (43 types), computed tomography (47 types), mammography (2 types), bone densitometry (4 types), conventional tomography (6 types) and dental radiology (33 types).

The set of healthcare providers which carry out radiodiagnostic examinations in Switzerland has been divided into four large categories: 1) 11 big hospitals with more than 500 beds, for which detailed annual statistics were requested, 2) hospitals with less than 500 beds, which participated in a fifteen day survey, 3) medical and dental surgeries and chiropractic clinics, which took part in a fifteen day survey (one week in the case of dental surgeons), 4) particular services (school, prison and army medicines, etc.), for which global annual statistics were requested.

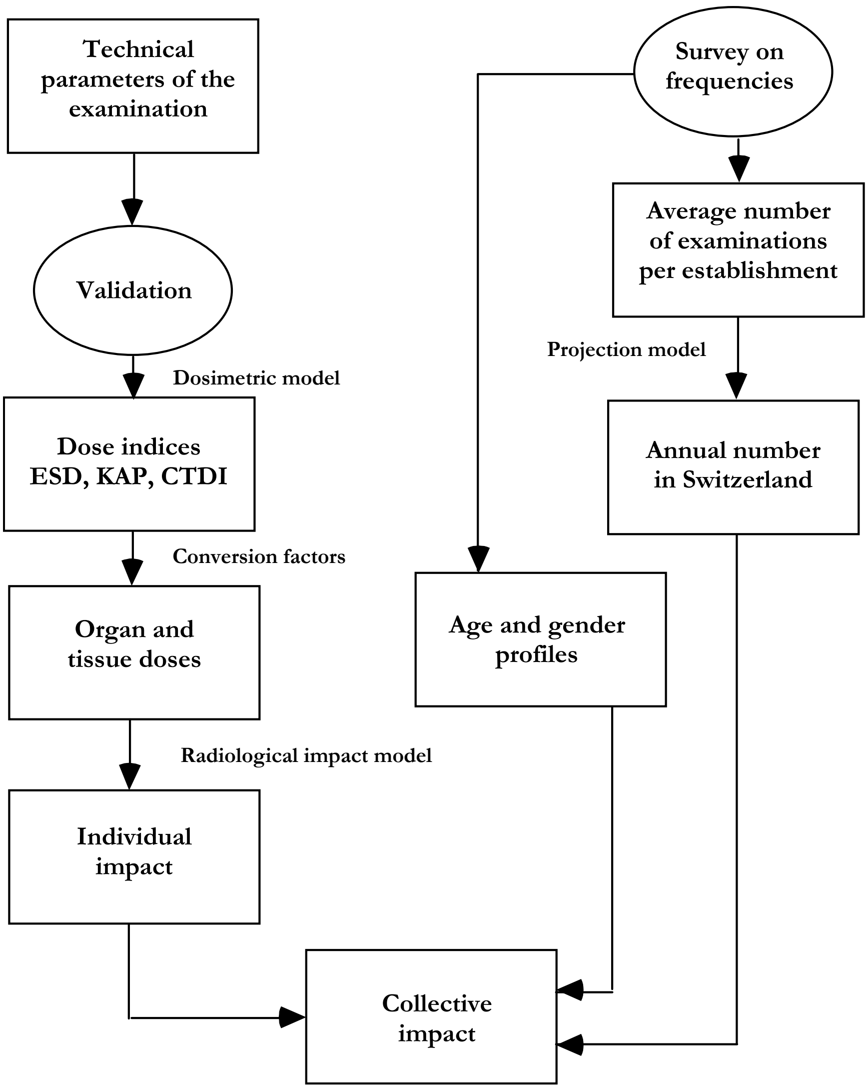


Figure 1. Methodology of the survey

More than 3000 healthcare providers were approached. The general practitioners (including general internists) were randomly sampled at a 20% rate and the dentists at 10%. For all the other specialties, the total number of healthcare providers was considered. A geographic stratification was performed using the most recent regionalisation system of Switzerland.

The questionnaire sent to the participants was structured around three axes: a) the equipment, that is the radiological unit and the films used, b) the radiological examinations; for each examination carried out during the survey it was a matter of recording the type of examination, the patient's age and gender, and answering three subsidiary questions pertaining to the prescription of the examination: nature of the affection, objective of the examination, and seriousness of the case, and c) the 1997 annual statistics of the number of examinations per type of examination.

The data convolution procedure consists of combining all the quantities determined by the survey to infer a quantity that measures the radiological impact of radiodiagnostics. Only the data contributing to the evaluation of the impact are taken into account. The collective equivalent dose corrected for age using the model (n), H^*_{col}, and associated to an organ (k) by an examination of type (i) in specialty (j) takes the form:

$$H^*_{col}(k, i, j, n) = \sum_{l,m} H(k, i, l) \times N(i, j) \times A(i, j, l, m) \times C(i, l, m) \times F_S(i) \times K(k, l) \times F(m, n)$$

$$= N(i, j) \times F_S(i) \times \sum_{l,m} H(k, i, l) \times A(i, j, l, m) \times C(i, l, m) \times K(k, l) \times F(m, n)$$

where

1. The annual number of examinations N depends on the type of examination (i) and the category of healthcare providers or medical specialty (j): N(i, j)

2.The equivalent dose to the organ is a function of the organ (k), the examination type (i) and the gender (l): H(k, i, l)

3. The fraction of examinations per age group varies with the examination type (i), the category of healthcare providers or medical specialty (j), the gender (l) and the age group (m): A(i, j, l, m)

4. The correction, if need be, for the sensitivity of the film-screen set depends on the examination type (i): F_S (i)

5. The correction for the build of the patient is a function of the examination type (i), the gender (l) and the age group (m): C(i, l, m)

6. The correction for age varies according to age group (m) and radiological risk model used (n): F(m, n)

7. The radiosensitivity of the organ depends on the organ (k): W(k)

8. The presence of the organ is a function of the organ (k) and the gender (l): K(k, l)

The collective effective dose corrected for age using the model (n), E^*_{col}, associated to an examination of type (i) in the specialty (j) is:

$$E^*_{col}(i, j, n) = H^*_{col}(k, i, j, n) \times W(k)$$

3. Results

3.1. Integral results

As shown in table 1 the survey revealed that around 9.5 million radiodiagnostic examinations are performed each year in Switzerland, i.e. 1.34 examination per caput. In terms of doses, the associated annual collective dose is of the order of 7100 Sv, which for a population of 7 096 894 corresponds to an average annual effective dose per caput of 1.0 mSv.

Table 1. Integral frequency and dosimetric results

	collective (x10^6)	*per caput*
Average annual number of examinations	9.5	1.34
Average annual dose (mSv)	7.3	1.03

3.2. Distribution with the category of examination

Table 2 presents the distribution of the annual number of examinations and the collective dose with the different categories of examination. In terms of the number of examinations, the radiography and dental radiology have the highest contributions to the total number (48% and 43% respectively). The other modalities represent together 9% of the total. In terms of dose, radiography, computed tomography and conventional fluoroscopy have the highest contribution to the collective dose (41%, 28% and 17% respectively). The other modalities represent 14% of the collective dose.

Table 2. Annual number of examinations and collective dose in mSv (rounded figures) per category of examination

Category	*Annual number*	*Fraction (%)*	*Collective dose*	*Fraction (%)*
Radiography	4’500’000	48	2’900’000	41
Dental radiology	4’000’000	43	72’000	1.0
Computed tomography	300’000	3.4	2’000’000	28
Mammography	200’000	2.3	43’000	0.61
Radiography & fluoroscopy	150’000	1.6	1’300’000	17
Angiography	70’000	0.74	550’000	7.8
Interventional radiology	30’000	0.28	260’000	3.6
Bone densitometry	30’000	0.34	40	0.0
Conventional tomography	10’000	0.12	48’000	0.68
Total	9’500’000	100	7’100’000	100

3.3. Distribution with the category of healthcare provider

Table 3 presents the distribution of the annual number of examinations and the collective dose with the different categories of healthcare providers. In terms of the annual number of examinations, the dentists are on top position with 42% of the total, followed by the hospitals with 31% and the general practitioners with 16%. The other categories contribute together for 11%. In terms of the collective dose, the hospitals alone contribute for about 73%. The general practitioners contribute for almost 10% and the radiology institutes for almost 7%. The contribution of the other categories all together is about 10%.

Table 3. Annual number of examinations and Collective dose in mSv (rounded figures) per category of category of healthcare providers

Category	*Annual number*	*Fraction (%)*	*Collective dose*	*Fraction (%)*
General and internal medicine	1'500'000	15.8	670'000	9.4
Radiology	250'000	2.6	480'000	6.8
Small hospitals (< 500 beds)	2'000'000	21.1	3'300'000	46
Big hospitals (> 500 beds)	950'000	10.0	1'900'000	27
Dental medicine	4'000'000	42.1	70'000	0.99
Chiropractic	60'000	0.6	140'000	2.0
Others	700'000	7.4	550'000	7.7
Total	9'500'000	100	7'100'000	100

3.4. Distribution with the age of the patient

The distribution of the collective dose with the age of the patient is given in figure 2. It peaks between 60 and 70 years and is quite different from that of the general population. The shift of the age distribution of the collective dose is estimated to about 15 years towards higher ages. If a correction for the age of the patient is performed according to an appropriate risk model, the mean annual effective dose is reduced to about 0.6 mSv per caput.

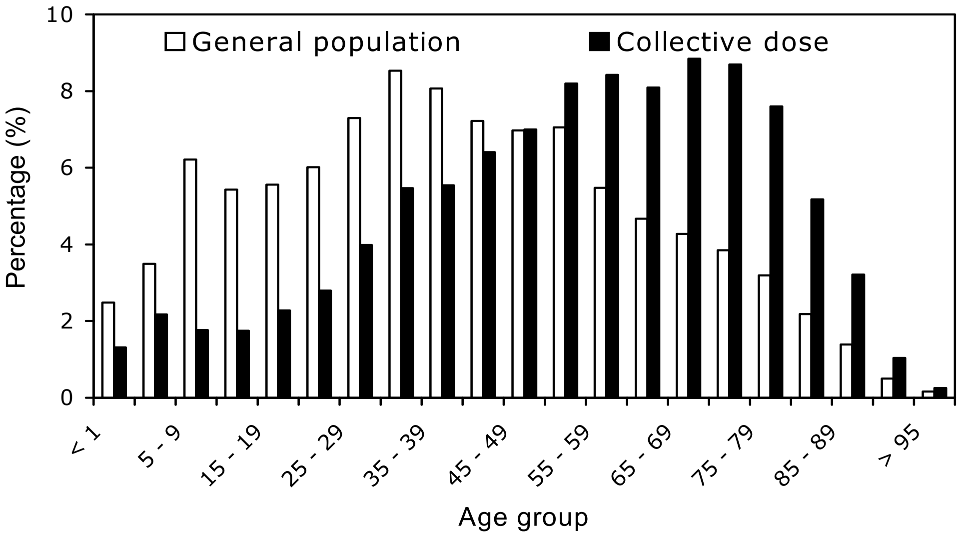


Figure 2. Distribution of the collective dose with the age of the patient

3.5. Data comparison

Table 4 compares the results found in this work with those reported by other countries of similar health care level. In general one notices a great variability of the reported data. The results of this study are within the range of variation and compare well with average values.

Table 4. Annual frequencies of X-ray examinations per 1000 population (1)

Country	Medical	Dental	Mammography	Angiography	Interventional	CT
Canada	892	–	79	7	0.31	41
Denmark	510	471	–	–	–	–
Finland	704	290	34	–	1.7	25
France	–	–	–	–	–	33
Germany	1254	276	68	24	2.2	64
Italy	–	–	–	–	–	29
Japan	1477	839	–	5.6	–	
Luxembourg	1046	469	50	13	–	76
Netherlands	598	182	47	0.63	1.3	32
Norway	708	–	–	11	–	48
Sweden	568	739	80	8.1	3	39
United Kingdom	489	212	27	5.2	4.5	21
United States	962	–	–	–	–	91
Average	920	310	25	7.6	3.0	57
Switzerland	760	581	31	9.9	3.8	46

Table 5 presents the results established by previous Swiss surveys. The annual number of X-ray views (or examinations) are compared with those found in this work. Relative to the 1978 data the total number of examinations appears to be roughly constant. However, the distribution with the different categories of examinations has changed significantly.

Table 5. Annual number of X-ray views (*examinations*) performed in Switzerland

Number of views	1957	1971	1978	1998
Diagnostics (medical)	2850	12491	12516	11686
Diagnostics (dental)	1102	2404	2992	4811
Fluorophotography	653	969	968	51
Total number	4605	15864	16476	16549
Total number of examinations	*5018*	*8555*	*8703*	*9530*

4. Conclusions

This survey provided valuable data on the situation of diagnostic and interventional radiology in Switzerland for the year 1998. The results indicate that around 9.5 million radiodiagnostic examinations are performed each year in Switzerland, i.e. 1.34 examination per caput, and that the associated annual collective dose is of the order of 7100 Sv, which corresponds to an average annual effective dose per caput of 1.0 mSv.

It appears that both the total number of examinations and the collective dose has not increased since 1970 but their distribution over the different modalities has changed drastically, and that Switzerland stands at the same level as other European countries in terms of number of examinations and collective dose.

At the end of this study a number of recommendations are suggested aiming at keeping the exposure due to diagnostic and interventional radiology as low as practically achievable.

The effort of dose reduction should cover all the modalities, but the types of examinations which contribute strongly to the total collective dose should receive special attention. With regard to radiographies, a particular effort should be made in order to encourage surgeries and radiology services of hospitals to conform to values recommended for the sensitivity of screen-film combinations. This would have an important direct effect on the doses given. As regards dental examinations, the dentists should be encouraged to use sensitive films (E class) as well as a rectangular collimator to reduce the needless irradiation of the patient.

The radiological detectors using screen-film combinations will be progressively replaced by digital systems. If this transition is well managed it could reduce the doses significantly (higher sensitivity for the same quality, saving data on over-exposed or under-exposed negatives). A reverse trend should not be ruled out, in particular if increasing the quality of the image is sought unilaterally. We recommend that the introduction of digital techniques be carefully monitored with regard to the doses to patients.

An effort should be made to reduce the effective dose per fluoroscopic examination, especially during angiographic and interventional examinations. The technical parameters must be optimised. The standard procedures prescribed by the manufacturers (series number, number of images per series, etc.) can often be simplified without degrading the diagnostic quality of the examination. Moreover, in the case of intensive examinations, the dose given to the patient must be accessible in real time during the examination to prevent exceeding the threshold of deterministic radiation effects. All fluoroscopic installations should be equipped with direct display instruments which measure the dose-area product.

With regard to CT examinations, the characterisation measurements of the CT scanners and the optimisation of examination protocols are important (number of passages, scanned volume, thickness and spacing of slices, etc.). They enable a significant reduction of the doses given.

The knowledge of the doses involved and the availability of guiding or reference values against which one can make comparisons are essential for all the examinations. Furthermore, it would be useful to establish a national dosimetric database for collecting all the measured doses to patients in Switzerland. Such a database should focus on angiography and interventional radiology (recording the values of the dose-area products on radiographic and fluoroscopic installations) and on CT (recording the values of the length-dose products on CT scanners). Clearly medical physicists would have a central role to play in such a programme. The database thus constructed and continuously updated should be made available to all institutions and individuals interested.

The process of reducing the doses in diagnostic and interventional radiology cannot be effective unless all the relevant parties are involved: patients, physicians, technicians in medical radiology, medical assistants and physicists.

In order to guarantee the efficiency of any dose reduction programme, it should be evaluated periodically with a quantification of the results by means of a follow-up mechanism. The impact of diagnostic and interventional radiology should be re-assessed by means of a smaller survey, ideally in a 5-year basis.

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3. DUTCH POPULATION DOSE FROM MEDICAL X-RAYS 2002

Els Meeuwsen

The latest estimation of the population dose from medical diagnostic examinations in the Netherlands is over the year 2002. The estimated average effective dose per capita is 0.52 mSv, nuclear medicine included. The estimated average annual effective dose due to X-ray examinations only is 0.45 mSv. Computed Tomography contributes 0.19 mSv to this amount. (www.rivm.nl/ims in Dutch).

Methods

Number of X-ray examinations in hospitals

The number of examinations in hospitals (intramural) is gathered from annual surveys. Every year Prismant[1], commissioned by the Dutch Association of Hospitals, collects a variety of data from the hospitals, including the total number of X-ray (without CT) and CT examinations. Since 2001 a supplementary survey, the Annual Survey Imaging Techniques, is sent along with the other annual surveys. This survey contains two parts, one on radiology examinations and the other on nuclear medicine. The radiology part contains the number of conventional X-ray (thorax, spine, mammography, other), diagnostic and therapeutic angiography (cardiac and other), contrast/fluoroscopy, X-ray guided interventions and bone densitometry (dexa). CT examinations are divided into head, thorax, spine, abdomen, pelvis, interventional and other. This survey is sent to all general and specialized hospitals. The survey includes a list of codes per category of examinations based on the Dutch system to declare expenses of health care examinations to simplify filling-in the survey. The academic hospitals, eight in total, have their own annual survey which provides the total number of X-ray and CT examinations.

For the year 2002 we received the total number of X-ray examinations from 95 hospitals out of 104, including the 8 academic hospitals. We estimated the total number of examinations for the missing 9 hospitals, based on the annual number of admissions to the hospitals. The distribution of the number of examinations per category as seen in the Annual Survey Imaging Techniques for the general hospitals is used to estimate the number of examinations per category in academic hospitals.

Effective dose per examination

From 2001 till 2004 a project called 'Demonstration project patient dosimetry radiology' was performed in the Netherlands [1]. In this project 11 hospitals carried out dose measurements for 48 clinical indications, divided into conventional X-ray, CT, mammography and fluoroscopy. The project was coordinated by LUMC Leiden (Teeuwisse, Geleijns, Veldkamp). Measurements of DAP, CTDI and Entrance Skin Air Kerma were carried out during the project. The used method for dose estimation for conventional X-ray was PCXMC Dose Calculation software with standard person (version 1.5.1. STUK-Radiation and Nuclear Safety Authority, Finland). For CT the ImPACT CT dosimetric calculator was used with 'scanner matching'. The CTDI was measured free in air and with a phantom (head and body). Measurements for mammography were carried out for three breast thicknesses (32, 53 and 90 mm). The Entrance Skin Air Kerma and the first half value layer were determined. And with these values the Average Glandular Dose was estimated based on the article of Dance et al. [2] among other. The effective dose for fluoroscopy examinations was determined by the measured DAP's with conversion factors in literature [3]. RIVM received the calculated effective dose (mSv) per examination. The weighted average effective dose per

[1] *a business organisation in the Dutch healthcare system*

examination was calculated based on the number and the effective dose data from the participating hospitals.

Outside of hospitals

There are three major fields taken into account concerning the use of ionising radiation for diagnostic purposes outside of hospitals (extramural): (1) mammography screening (2) tuberculosis screening (3) dental radiography. The number of mammography screening examinations is derived from the National Evaluation Centre for Breast Cancer Screening (LETB) over the year 2000. The estimated average glandular dose was provided by the National Expert and Training Centre for Breast Cancer screening (LRCB) based on personal communication for the estimation of 1998 [4]. The annual number of tuberculosis screening examinations is based on personal communication with an expert and two reports (centre for people who seek asylum and of people who stay in penitentiary). The dose per screening is derived from the Demonstration project. For dental examinations the data from the 1998 survey [4] are used.

Results

The total number of X-ray examinations in 2002 in the Netherlands is estimated at 13.7 million. This annual number related to the Dutch population of 16 million people results in 847 examinations per 1000 population. If the number of extramural examinations is excluded, the total number is 483 per 1000 population.

The overall estimated annual average effective dose per X-ray examination in 2002 is 0.53 mSv. The estimated annual effective dose is 7,300 man Sv, which gives an annual effective dose of 0.45 mSv per capita. An overview of the examination frequency, the average effective dose per examination and the average annual effective dose per capita is shown in figure 1.

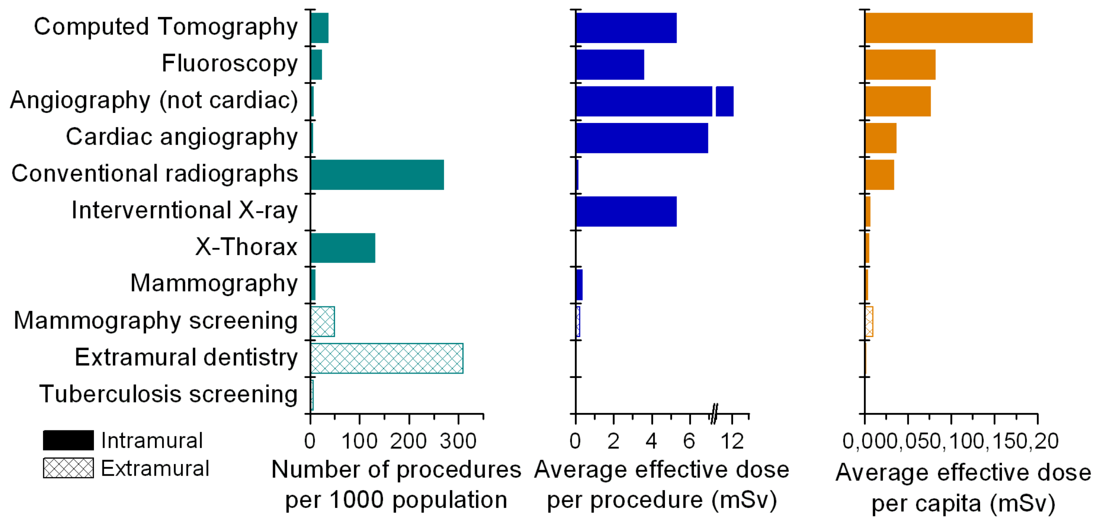

Figure 1 Examination frequency, average effective dose per examination and the average annual effective dose per capita for different types of x-ray procedures. The solid bars represent procedures inside hospitals, the shaded bars represent extramural examinations.

Conclusion and discussion

The average annual effective dose per capita from X-ray examinations has slightly decreased from 0.52 mSv in 1998 to 0.45 mSv in 2002. Computed Tomography contributes the largest part to this number, 0.19 mSv. The following list of items is provided to show some difficulties and uncertainties by estimating the average annual effective dose per capita.

•The Demonstration project, as carried out in the Netherlands, has provided extensive dose data for estimating the average annual effective dose per capita. The representativeness of the hospitals who participated in the Demonstration project is unknown. There are two academic hospitals out of eleven hospitals that participated in the project. In the Netherlands there are eight academic hospitals out of a total of more than a hundred hospitals.
•Participation to the project was voluntarily which could mean that the participating hospitals are more focused on radiation protection than non-participating hospitals.
•The difference in protocols between hospitals for the same clinical indication leads to a substantial difference in effective dose.
•Dose measurements were made for 48 clinical indications and extrapolated to the other examinations.
•The relation between registered procedures in hospitals and a complete examination based on clinical indications is unknown.
•The distribution of different categories of examinations in academic hospitals is uncertain, it is based on the information of general hospitals.
•The number of examinations outside hospitals is not gathered on a structural base except for mammography screening.
•There are no data available from private hospitals and other extramural institutes beside the ones mentioned above. Their contribution is unknown.
•There is no structural base of collecting dose data from X-ray procedures in the Netherlands.

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4. GERMAN POPULATION DOSE FROM MEDICAL X-RAYS 1996-2003

Elke Nekolla & Jurgen Griebel

The Federal Office for Radiation Protection (BfS) has been collecting and evaluating data for medical radiation exposure in Germany from the beginning of the 1990's. With the amended "Röntgenverordnung" (x-ray Ordinance) coming into force in 2002, the BfS was assigned the official task to regularly assess medical radiation exposures of the general population. In the most recent evaluation data of the years 1996 to 2003 were included.

MATERIALS AND METHODS

1. Frequency data

Information on annual frequencies of x-ray diagnostic procedures was mainly obtained from German health insurance companies, namely the National Association of Statutory Health Insurance Physicians and the Association of Private Health Insurers. In Germany, the statutory health insurance (SHI) is the main source of healthcare funding. For most Germans SHI membership is compulsory. About 350 sickness funds are covering almost 90% of the population. About 9% of the population have full-cover Private Health Insurance (PHI). There are two different medical fee schedules in Germany, i.e. reimbursement catalogues, one for the SHI funds (EBM = Einheitlicher Bewertungsmaßstab [=uniform value scale]) and one for the PHI funds (GOÄ = Gebührenordnung für Ärzte [=medical fee schedule for physicians]).

In these reimbursement catalogues, a great number of the physicians´ services, i.e. the different kinds of medical attendance and thus also the radiological examinations, are accounted for via special codes (Example: GOÄ 5100 = two-view examination of cervical spine).

There are about 120 codes referring to GOÄ, and about 90 corresponding to EBM covering about 70 examination types. Several EBM as well as GOÄ codes refer to additional views or series or to an overhead due to the use of digital radiology, computer aided picture analysis etc. These codes are not accounted for in case of frequency estimates. Codes which refer to additional views/series are accounted for in case of dose estimates. Both, the GOÄ and the EBM codes were arranged according to type of diagnostic procedure and/or region of examination. To achieve a standardisation, 19 broader examination categories were created in total:

- Dental
- Head
- Shoulder
- Thorax
- Abdomen
- Pelvis/hips
- Extremities
- Spine
- Mammography
- Upper GI tract
- Lower GI tract
- Urinary tract
- Bile tract
- Osteodensitometry
- CT
- Arteriography
- Venography
- Interventional procedures

- other and unassignable examinations

According to international standards, the term "examination" includes all x-ray applications which – referring to one organ – are required to answer a clinical question by means of an x-ray modality. E.g. a two-view chest x-ray examination combined with fluoroscopy is considered to be one examination.

A standardised method has been developed to permit a consistent evaluation of time series and thus a trend analysis. Beware of the fact that systematic errors cannot be completely avoided, the BfS method of data assessment aims at keeping these errors at least constant in order to be able to recognise trends as early and as reliable as possible.

Complete code numbers are obtained for SHI out-patients, i.e. for about 70% of all x-ray examinations.

For privately insured patients, total frequencies are determined on the basis of random samples taken separately for in-patients and out-patients by the PKV. Sample sizes comprise for about 0.1% of the total account number. In 2003, x-ray applications paid by private health insurance funds account for about 15% of all x-ray diagnostics in Germany where about 2/3 refer to out-patients.

Code numbers for SHI in-patients have to be estimated from out-patient data. "In-patient to out-patient ratios" for the various examination categories were estimated by means of data from a recent research project which evaluated the frequency of x-ray diagnostics in German hospitals for the year 2002. Using these ratios, in-patient examination frequencies were extrapolated from out-patient numbers. Due to small numbers in the private in-patient sector, it was decided to use this approach for the total in-patient sector, not only for SHI in-patients. About 20% of x-ray applications in 2002 are assigned to German in-patient facilities.

In Germany, a clear allocation of codes to certain x-ray diagnostic procedures or to certain body regions or organ systems is not always possible since in certain cases the same code is used for different x-ray applications or various body regions. For example one single code (GOÄ 5030) refers to x-ray applications of the extremities, the shoulder and the pelvis. A recent research project has estimated the proportional fractions of allocations of body regions in these "accumulative codes" for in-patients. Another research project has been planned for out-patients. As long as there are no data for out-patients, the estimates for in-patients are used for both in-patients and out-patients.

2. Effective dose per examination type

The effective doses per examination type for radiographic and radioscopic examinations were calculated using measured quantities and conversion factors from these measured quantities to effective dose. The conversion factors were either obtained from literature (e.g. NRPB-R 262) or by using the software X-RAY DOSIMET-RG which is based on the results of Monte Carlo calculations with anthropomorphic phantoms (GSF report 11/90). The basic quantities measured were mainly KAP, but also Airkerma K_A or kV and mAs values. These were collected for frequent examination types in 1997 to 1999 in selected German hospitals. In some cases also KAP measurements performed in 1992 to 1994 were taken into account. For examination types, where measured data were not available, assumptions were made concerning e.g. fluoroscopy time and KAP per minute. The effective doses for CT examinations were estimated on the basis of data of a nation-wide CT survey in 1999 (Galanski et al.) using the software CT-EXPO which is based on the results of Monte Carlo calculations with anthropomorphic phantoms (GSF report 30/91) and additionally applies scanner type specific correction factors. These calculated doses were evaluated for a number of scanner types by measurements using TL dosimetry and the anthropomorphic Alderson phantom (Brix et al.).

3. Collective effective dose

The annual collective effective doses from x-ray diagnostics were obtained by multiplication of the estimated effective doses per examination type with the corresponding annual frequency, and summation over all types of examination.

RESULTS

Compared to other industrialised countries, Germany is in the upper range with approx. 1.7 x-ray examinations in the year 2003. On the one hand, a decreasing trend in the overall frequency of x-ray examinations was observed during the period 1996 to 2003 (see figure 1). On the other hand, the mean effective dose per capita shows an increase from about 1.6 mSv in 1996 to about 1.7 mSv in 2003 (see figure 2). This rise can mainly be attributed to the increased application of CT. CT contributes about half of the total cumulative effective dose in 2003 despite the fact that it contributes only about 6% to overall x-ray procedures (see figure 3).
In contrast to CT examinations, the number of conventional x-ray examinations of the chest and of the abdomen (including digestive, bile and urogenital tract) is decreasing.
Dental x-ray diagnostics account constantly for about one third of the total number of x-ray examinations. Apart from dental x-ray examinations, x-ray examinations of the skeleton (i.e. head, shoulder, spine, pelvis/hip, extremities) and of the thorax are the most frequent (see figure 3).

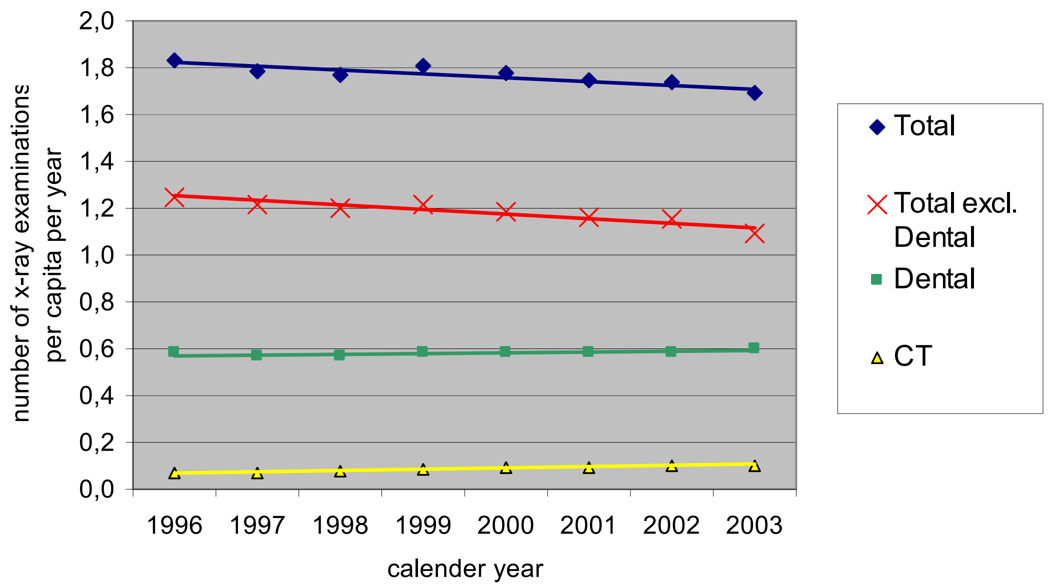

Figure 1: Annual number of medical and dental x-ray examinations per capita in Germany for 1996 to 2003

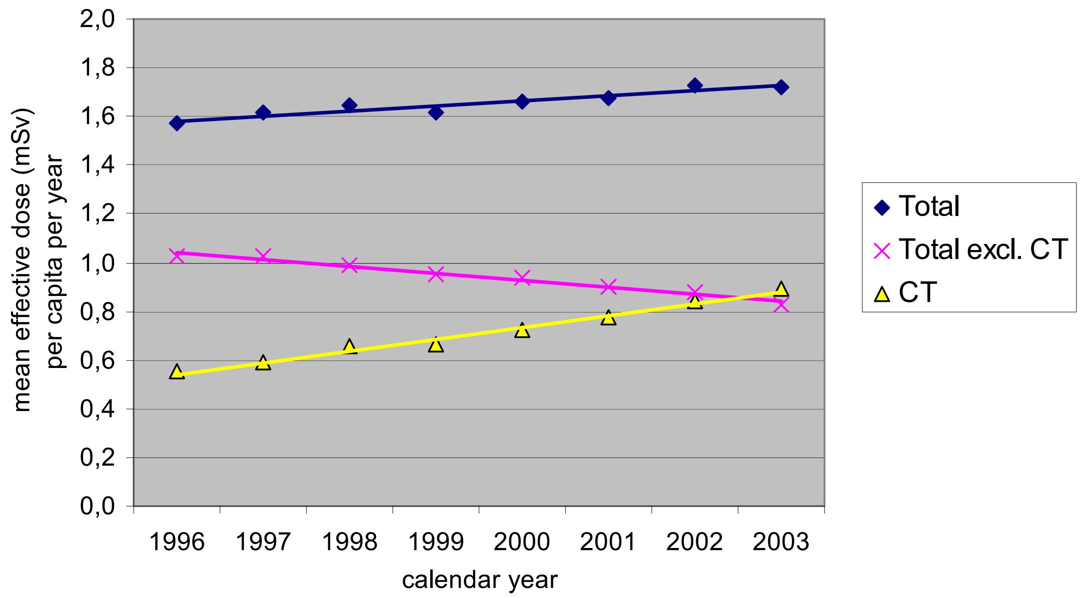

Figure 2: Annual effective dose (mSv) per capita due to x-ray diagnostics in Germany for 1996 to 2003

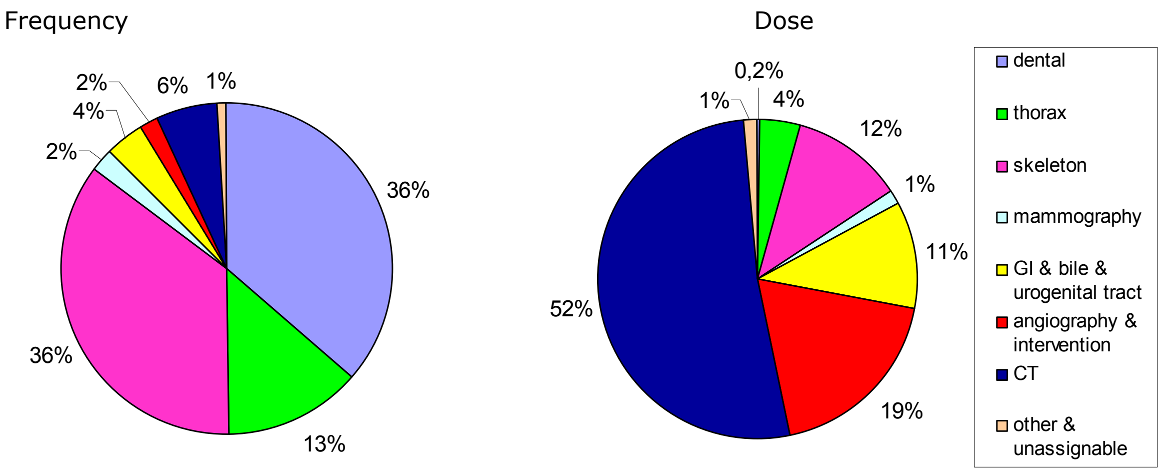

Figure 3: Relative frequencies (left panel) of various x-ray examination categories and their relative contribution to the collective effective dose (right panel) in 2003.

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5. FRENCH POPULATION DOSE FROM MEDICAL X-RAYS 2002

Bernard Aubert, Pascale Scanff

Introduction

The only nationwide survey on medical X-ray practices in France was carried out more than fifteen years ago [1]. Since then, only some smaller and targeted studies were performed. Their results and conclusions were published in internal reports only [2] and up to 2005, no consistent data concerning both the nature and frequency of X-ray diagnostic procedures and the associated dose were available at the national level. However, with the implementation of the European Directive 97/43, the knowledge of medical practices is necessary and the question of the population dose resulting from medical X-ray examinations is raised again. In order to provide French data concerning the medical exposure to ionising radiation and to follow this exposure over the years, the Institute for radiation protection and nuclear safety (IRSN) and the national institute for public health surveillance (InVS) decided to coordinate their efforts and to share their sources of information to build up an observatory of medical exposure to ionising radiation. A first study was carried out in order to evaluate the nature and frequency of radiological diagnostic procedures and associated doses. This work updated the detailed dose estimate for the year 2002, using institutional data from the French health care system for the nature and frequency of exams and some recent information on patient doses from the diagnostic reference level (DRL) campaign completed with European data. This work mainly focused on the exposure during conventional radiological procedures and computed tomography exams.

Methods

Number of examinations

The radiological examinations are performed either in the liberal sector by private practitioners or in public hospitals within the course of a hospitalization or not. If a liberal radiologist realises the examinations, patients have to pay their exams and are refunded by the main health insurance (CNAM), which covers more than 98% of the French population. Acts are thus traced by CNAM. For the acts carried out in the public hospitals, situation is quite different: either patients are not hospitalised and the procedures may be the same as for private units, either cost of acts enters into the hospital foundation given by the government department of health. In this last case, acts are then integrated in the assessments of activity of the hospitals and traced by the government department through the national statistics of public health establishments (SAE). These two main sources of data: CNAM and SAE were thus consulted. The limits between the two data sources were not really clear because of the acts realised in hospitals without hospitalisation, which may be counted in the CNAM database or in the SAE database or the both. To evaluate the total number of acts, two assumptions can thus be advanced: *(i)* a **"low hypothesis**" in which one supposes that there is a strong covering between the CNAM data and data SAE for the exams carried out for non-hospitalised patients. According to this assumption, the sum of the acts recorded in the CNAM data base and the acts carried out for the establishment itself in the SAE is then retained; *(ii)* a **"high hypothesis"** in which one supposes that there is no covering between the CNAM data base and the SAE database (for the establishment and the outside of the establishment). According to this assumption, it is advisable to add the values of the two data sources.

Effective dose per examination

Only few data are now available about the doses associated with the exams in France. The most recent data and thus the closest to the current practices come from the results of the French measurement 2001-2003 campaign for the establishment of the diagnostic reference levels (DRL). From April 2001 to February 2003, a first French campaign of dosimetry in diagnostic radiology was carried out under supervision of a steering Committee, involving representatives of scientific and professional societies and of DGSNR and experts of IRSN [3,4]. In 24 volunteer radiology departments, patient dose measurements were performed. For each of the 8 examinations selected, 4 in Conventional Radiology (CR) and 4 in Computed Tomography (CT), data and dose measurements were assessed for 20 adult patients in each centre. Medical physicists established protocols and data sheets. IRSN was in charge of the processing of measured and collected data. In CR, the entrance surface dose for each exposure was measured on 1231 patients using thermoluminescent dosimeters. From these values, the effective dose per examination type was calculated using X-DOSE software. In CT, the weighted Computed Tomography Dose Index (CTDIw) and the Dose-Length Product (DLP) were calculated for 667 patients, on the basis of procedure parameters and scanner normalized dose index values. The mean effective dose per examination was calculated by using conversion factors of the "European guidelines on quality criteria for computed tomography" (EUR 16262 EN). For the other examinations non-included in this campaign, values published in the report "Protection against radiation 118" of the European Commission were retained [3]. In the absence of data in these two sources, those of the NRPB- W4 report of March 2002 [4] were taken.

Results

Number of examinations

The analysis of the data provided by the CNAM database and SAE showed that 77 different procedures in conventional radiology have been listed and the total number of each of them was estimated. The results show that between 55.4 and 65.9 million of acts (according to the two hypothesis) have been realised in conventional radiology in 2002 (table 1). One third of these acts corresponded to dental examinations. The analysis of the data concerning all exams excluding dental radiology leads to an annual number of acts of radiology between 36.9 and 47.5 million. The distribution of the acts of conventional radiology showed that the radiography of the lung remained always the most frequent act (from 4 to 5.3 million per year) followed by the bilateral mammography (from 4.0 to 5.1 million, screening mammography excluded). All radiographies concerning the limbs reached from 12.2 to 15.8 million, representing 1/3 of the conventional exams dental excluded. In computed tomography 29 different procedures were considered. The total exam number in computed tomography reached between 4.2 and 6 million according to the low or high hypothesis (table 1). The head and the spine examinations represented respectively 37 and 26% of the total. The examination of the abdominal region, chest and limbs represented 18, 12 and 7 % of the total respectively.

Table 1: *Number of examinations in 2002 (in million) for the whole French population (61.4 million) in CR and CT for the low or high hypothesis.*

Hypothesis	Low	High
Conventional radiology	**55.4**	**65.9**
Head and neck	*2.0*	*2.6*
Chest	*4.9*	*6.3*
Abdomen / pelvis	*2.2*	*2.8*
Spine	*6.9*	*8.9*
Pelvis / hips	*3.8*	*4.9*
Limbs	*12.3*	*15.8*
Breast	*4.9*	*6.2*
Dental	*18.4*	
Computed tomography	**4.2**	**6.0**
Head and neck	*1.5*	*2.2*
Chest	*0.5*	*0.7*
Abdomen / pelvis	*0.8*	*1.1*
Spine	*1.1*	*1.6*
Limbs	*0.3*	*0.4*

Effective dose per exam

Results of French campaign 2001-2003

The results for the eight examinations are presented below in table 2 for the four exams in conventional radiology and in table 3 for those in computed tomography. Values obtained during this campaign were very close to that of the publication 118 of the European community either lower as for abdomen without preparation (0.58 vs 1.0), either higher as for chest examination (0.05 vs. 0.02).

Values of the European community and NRPB-W4 report

Values of the European community for eight examinations in conventional radiology were kept and all other values in conventional radiology as well as in computed tomography were retained from the NRPB data.

Table 2: *Mean entrance surface dose ESD (mGy), standard deviation and mean effective dose per type of examination for the whole group of patients studied in CR during the 2001-2003 French campaign.*

Examination	Chest P - A	Abdomen A - P (plain film)	Lumbar spine A - P	Lumbar spine Lateral
Number of installations	25	21	12	12
Number of patients	511	331	195	194
Mean ESD (mGy)	**0.28**	**5.2**	**8.2**	**19.5**
Standard deviation (mGy)	0.19	5.3	8.3	12.9
Conv coeff. (mSv/mGy)	0.164	0.111	0.100	0.020
Mean Effective dose (mSv)	**0.05**	**0.58**	**0.83**	**0.39**

Table 3: *Mean values of CTDIw, DLP and mean effective dose per type of examination in CT calculated from the 2001-2003 French campaign.*

Examination	Routine chest	High Resolution lung	Routine abdomen	Routine head
Number of installations	16	11	16	12
Mean CTDIw (mGy)	**13.8**	**24.5**	**14.6**	**47.3**
Mean DLP (mGy.cm)	**324**	**78**	**449**	**787**
Conv coeff. (mSv/(mGy.cm)	0.017		0.015	0.0023
Mean Effective dose (mSv)	**5.5**	**-**	**6.7**	**1.8**

Per caput effective dose

Firstly, a "collective" dose was calculated for each examination type. The sum of all of these doses gives the collective dose. The per caput effective dose was then obtained by dividing the collective dose by the number of inhabitants. This estimation was done according to the two hypotheses. The calculated per caput effective dose from both conventional radiology and computed tomography led to values between 0.48 and 0.64 mSv for the year 2002. Finally the per caput effective dose reached between 0.66 and 0.83 mSv with the contribution of nuclear medicine and interventional radiology [5].

Conclusion

The new evaluation of medical exposure to ionising radiation for the year 2002 showed values in the mean of European countries. It indicates that conventional radiology and CT represented respectively around 90 and 8% of the total diagnostic examinations using ionising radiation; acts in nuclear medicine and interventional radiology representing both 2%. However these last exams represented between 23 and 28% of the dose delivered to the French population whereas the acts in CT contributed for 38 to 40% i.e. as conventional radiology.

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6. NORWEGIAN POPULATION DOSE FROM MEDICAL X-RAYS 2002

Ingelin Børretzen I, Hilde Olerud, K Bakke

Introduction

Nationwide surveys have been carried out to assess the numbers of radiological examinations conducted in Norway during the years 1983, 1988, 1993 [1] and 2002. The following provides an overview of the applied methods and results from the most recent work carried out to estimate current frequencies of radiological examinations and the corresponding collective and per capita effective doses in Norway.

MATERIAL AND METHODS

The 2002 survey covers all examinations employing X-rays, MRI and ultrasound for medical diagnostic purposes at all hospitals and clinics (131 institutions) excluding dental, chiropractic and photofluorographic purposes, and bone densitometry. All in all, 72 public hospitals, 9 private hospitals, 25 private radiology enterprises and 25 mammography screening laboratories are included in this survey.

The number of examinations was generally reported from each hospital or clinic as the number of examination codes. These were provided in detail by the radiological management systems (six different systems in Norway). The code system was designed by the Norwegian College of Radiology [2], and had been adopted by nearly all hospitals and clinics by 2002. This code system forms the basis for the reimbursement scheme in Norway. However, it was not developed into such an extent that the number of examinations could be collected directly, due to the fact that one examination could generate more examination codes. Nevertheless, the collection of examination codes in the form of printouts from the radiological management systems was assumed to yield better results when considering response rate and reliability of data, than the alternative, that is distribution of questionnaires (applied in previous surveys).

Methods for estimation of the actual numbers of examinations conducted from the reported numbers of examination codes is currently in focus. Differences in the complexity of the examinations and ambiguities in the code system itself require a separate assessment for each modality. It has been observed that more complicated examinations in terms of more procedures, or more acquisition series carried out per examination tend to generate more examination codes. With this in mind, it is clear that determining the number of MRI, CT and ultrasound examinations is rather challenging, while conventional X-ray examinations is a simpler task. It is assumed that the number of examinations and number of examination codes are basically equal with regard to conventional X-rays.

The collective effective dose is calculated from the total number of examinations and the mean effective dose per examination. The frequency of a specific radiological examination type is assumed to change more rapidly than the mean effective dose per examination. Thus, the mean effective dose per examination from the latest countrywide dose survey as published in 1997 [1] is supposed to be still valid for most of the examinations.

RESULTS

Trends in examination frequencies from 1983 to 2002

Trends in examination frequency, i.e. the number of examinations per 1000 inhabitants from 1983 to 2002, are shown in figure 1 for the four modalities of medical imaging included in this study. The frequency of conventional X-ray examinations has remained rather stable over the 20 year period in question, while a rather dramatic increase in the use of the remaining modalities took place. The examination frequencies of MRI, CT, and ultrasound have increased by a factor of 11, 2 and 0.5, respectively, since 1993. Notably, the spread of more recent technologies (MRI, CT and ultrasound) has not lead to a corresponding decrease in the conventional X-ray examination frequency, conversely the decrease in conventional X-rays was by only 4 % from 1993 to 2002.

During the period from 1993 to 2002 the total frequency of radiological examinations has increased from 788 to 910 per 1000 inhabitants, while the frequency of radiological examinations applying ionising radiation has increased from 710 to 742. The 20 most frequent radiological examination types all modalities taken into account are given in figure 2. Four CT examination types are now among the top 20 examination types and CT examination of the head/brain is nearly as frequent as X-ray examination of the knee. Ultrasound of the abdomen and MRI examinations of the head/brain are the top two non-ionising radiation examinations, US abdomen conducted at about the same frequency as conventional X-rays of the ankle and MRI head brain at the same frequency as CT lumbar spine.

Collective effective dose estimate

The mean effective dose per inhabitant from radiological examinations is estimated to 1.1 mSv for the year 2002, which represents an increase of 40 % since 1993. The contribution from CT was found to amount to 59 % of the total CED.

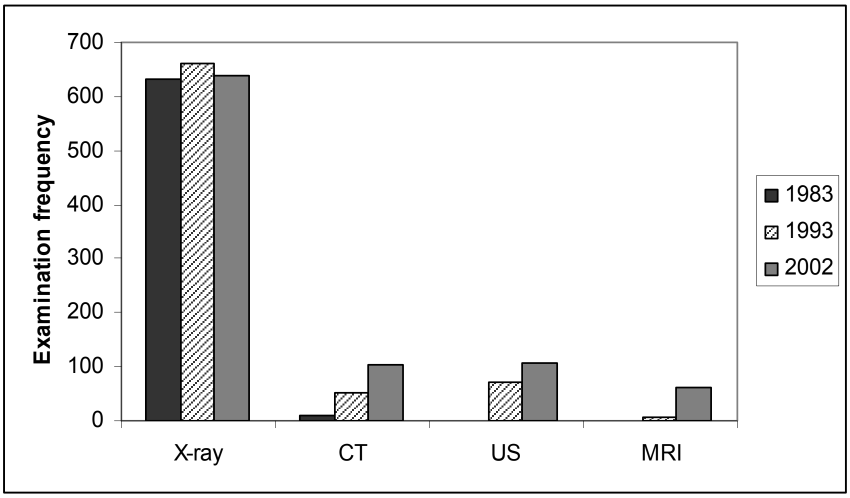

Figure 1. The trends in examination frequencies, (no of examinations per 1000 inhabitants) for each of the modalities CT, MRI, ultrasound (US) and X-rays from 1983 to 2002. Frequencies of MRI and ultrasound exams are only available from 1993 and 2002.

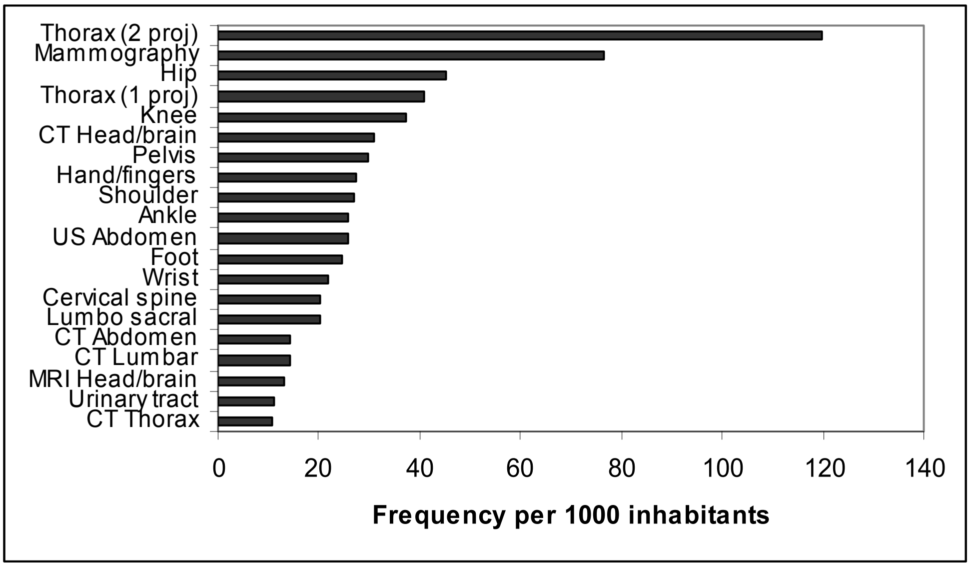

Figure 2. Frequencies per 1000 inhabitants of the 20 most common radiological examinations in 2002 all radiological modalities taken into account.

DISCUSSION

Frequency data

The main advantage of obtaining data directly from all the hospitals and clinics is that the data sets are guaranteed to be based on actual examinations. Furthermore, it allows studies of possible geographical variation in the use of radiological examinations across the country.

The system for coding X-ray procedures has been developed since the eighties and has been available in various versions which necessarily complicate the trend analysis. In earlier versions the number of codes was less and the codes not so specific as today, i.e. the difference between the number of codes and the number of examinations was less than today, but the examined body regions were not described as accurately. The 2002 versions specificity leads to the possibility of generating more than one code per examination performed, which introduces uncertainties in the frequency estimates. Consequently, the code system designed by The Norwegian College of Radiology should be developed further in order to accommodate a consistent description of radiological activity.

Dose estimates

Reports from other European countries, for example from UK [3], show a reduction of the effective dose per examination for several conventional X-ray examination categories due to an increased attention to dose optimisation, among other factors. In Norway, no significant dose reduction is expected yet since dose optimisation not has been stressed until recently through new regulations [4] which are in compliance with the "Patient directive" [5] when it comes to important issues like the principle of justification, optimisation and patient dose monitoring. In the future, patient dose measurements are expected to be performed by the hospitals and clinics, and the results preferably collected in central databases. This will give better dose statistics compared to previous dose surveys performed by means of inspectors from NRPA who travelled from hospital to hospital [1]. The majority of the radiological departments in Norway now apply digital technology. How this affects patient doses needs to be investigated. For now, mean effective doses per examination are assumed to be practically unchanged since 1997.

CONCLUSION

The observed small reduction in the frequency of conventional X-ray examinations does not outweigh the large increase in CT, MRI and ultrasound examinations. Therefore, the total frequency of radiological examinations is increasing, the non-ionising modalities showing the most significant growth. The increased collective effective dose is primarily caused by the increased CT examination frequency.

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7. SWEDISH POPULATION DOSE FROM MEDICAL X-RAYS

Wolfram Leitz

Summary

Nationwide surveys on X-ray practices in Sweden have been performed in the mid 70-ties and mid 90-ties. Two different approaches were used and the results of both of them are judged to be quite reliable. In between these two surveys and after the last survey a number of more limited surveys on dose and frequency were conducted. Different techniques and methodologies were used in the various surveys, each having its advantages and disadvantages. The experiences gained could be a valuable input when deciding upon preferred harmonized methods for the assessment of the frequency and of the dose from x-ray examinations.

Introduction

The Swedish Health Care System is basically public and organised in some 30 health counties (landsting). Private clinics and hospital exist but they account for less than 10 % of the radiological examinations performed in Sweden. All clinics using ionizing radiation must have a licence from SSI. SSI is supervising the clinics by inspections, regulations and by collecting data relevant for radiation protection issues. Several investigations have been conducted during the past decades concerning practices, frequencies and doses from diagnostic radiology. The most important from the last years are described below, together with a short discussion on the pros and cons of respective method.

Surveys in Sweden during the last 30 years

National Survey x-ray examinations 1974-76 (1)

Aim: to assess the radiation dose and risk from diagnostic x-ray examinations in Sweden. Method: Measurements were conducted by the staff of SSI in 13 hospitals with DAP-meters combined with TLDs (for estimation of organ doses) for around 1000 patients. Energy imparted was calculated from the DAP-value using conversion factors by Carlsson (2) and organ doses from TLDs. Whole body doses were assessed by dividing the energy imparted with the body mass. Detailed information was in those days available on frequencies of radiological procedures from the National Board of Health and Welfare.

Results: In Sweden were performed 650 medical examinations and 1500 dental exposures per year and 1000 inhabitants, the average whole body dose per inhabitant was 1 mGy.

National survey on mammography 1981-1984

Aim: to assess the variation of doses from mammography in Sweden together with parameters that are relevant for the dose.

Method: The staff of SSI performed the measurements. For clinical settings the entrance and the exit surface exposure was measured for PMMA phantoms of thickness 1 to 7 cm. Average absorbed doses were calculated based on the measured depth dose curve. All mammographic equipment was included in this survey (around 60 units). Frequency of examinations was not searched for.

Results: The average absorbed dose in a 50 mm thick PMMA-phantom was 1 mGy The measured doses gave a valuable contribution to the discussion on how general screening with mammography should be performed, among other things for the establishment of guidance levels.

National survey on chest examinations (3)

Aim: to assess the radiation dos from PA chest examinations in Sweden together with for the dose relevant parameters.

Methods: The chest LucAl-phantom from the CDRH (Center for devices and radiological health, the US federal agency on radiation protection) was used in this survey. With the clinical settings for PA chest examinations and the LucAl phantom in place of the patient exposures were performed and

the entrance surface exposure was measured. Additional tests such as film processor characteristics, sensitivity of the imaging system and image quality assessment were performed. The staff of SSI performed roughly 15 % of the measurements, medical physicists after instruction the rest. All chest stands in Sweden were covered, around 440 units. Individual feedback was given to all clinics with indication on how to proceed for reducing the dose. The frequency of examinations was not evaluated in this study.
Results: A large spread of the entrance surface exposure was found (a factor of more than 30) and the influence of various parameters on the dose was evaluated.

National survey on CT-practises 1991 (4, 5)
Aim: To assess the collective dose and the dose distribution from CT-examinations in Sweden with respect to age, sex, type of examination and CT-scanner.
Methods: Templates were sent to all clinics using CT-scanners with the obligation of recording all relevant data for all CT-examinations during one week. This included patient data (age, sex), clinical request for the examination, frequency of CT-examinations, all relevant exposure settings such as tube voltage, tube loading, nominal slice width, and number slices. Data from 89 CT-scanners comprising some 3800 patients were reported and analysed. By scaling from one week to one year the dose, age, examination type distribution was derived and the collective dose was calculated. The staff of SSI measured the dose for all types of CT-scanners using standard dosimetry phantoms and a pencil shaped ionisation chamber.
Results: By scaling to one year the annual frequency of CT-examinations was found to be 200000. 60 % of all examinations were in the head region, the collective dose was 1000 manSv per year.

Follow-up of CT-practices 1996 (6)
Aim: To check the development of CT-practices since the 1991 survey with respect to frequency of CT-examinations, and to what extent the exposure parameters are adapted to the anatomical size (children, adults of different sizes) and to anatomical regions (thorax vs. abdomen).
Methods: Questionnaires were sent to all contact persons with forms to be filled in: standard protocols for thorax, abdomen, head, and how these protocols are modified for different anatomical sizes. The frequency of CT-examinations was also asked for. Approximately 65% of the contact persons responded, and the reported data were scaled to 100%.
Results: Compared to the 1991 survey large changes had occurred. The number of CT-scanners increased from 90 to 112, the number of annual examinations from 200000 to 350000 and the collective dose doubled from 1000 to 2000 manSv per year. Adaptation to anatomical size is performed in two out of three facilities.

National survey covering all x-ray examinations from 1995 (7).
This is the most recent national survey conducted in Sweden
Aim: To investigate on a national level the dose, frequency, sex and age distribution for x-ray examinations, in accordance to the questionnaire from UNSCEAR.
Methods: All licence holders were requested to fill in a questionnaire concerning the frequency (age and sex specific) and dose for 15 broadly defined x-ray examinations. The response was rather poor: The licence holders giving data on frequencies covered only 25% of Sweden’s population with radiological services and for patient doses this figure was 6%. The figures for the frequencies were multiplied by four to be valid for the whole country. For the doses the average of the (few) reported data was taken.
Results: The data were reported to UNSCEAR and are published in the 2000 UNSCEAR report (7). The number of annual medical x-ray examinations was 570 and that for dental examinations 740 per thousand inhabitants. Collective dose 6000 manSv, which means 0,7 mSv per year and inhabitant.

Pilot study before introducing diagnostic reference levels in Sweden 1999 (8).

Aim: To check whether suggested examinations and numerical values for DRL are suitable to be introduced into Swedish regulations.

Methods: All health counties (around 30) were asked to measure doses for twelve specified x-ray examinations, every examination at one x-ray stand each comprising at least 20 patients. These were five conventional, six computed tomography and one mammographic examinations. Data was also collected concerning the total number of the respective examination in each health district and how many of these were performed on children. Data from approximately 8 000 patients were received and evaluated.

Results: Both the measured doses and the reported frequencies were in reasonable agreements with the figures found in the national survey 1995, suggesting that both surveys are reliable. The results were taken into consideration in SSI's regulations on diagnostic reference levels issued 2002 (9).

Diagnostic reference levels

The concept of diagnostic reference levels (DRL) has been introduced into Swedish regulations in 2002 (9). DRL have been established for 12 examinations and the results were to be reported to SSI by fall 2004. Up to now data for some 1400 examination/x-ray stand combinations have been reported comprising some 30 000 patients. Although the primary aim with this concept is to identify practices with unusual high patient doses, the data can be used for a fairly good estimation of the patient doses. For the assessment of the collective dose the frequency of the examinations is needed. SSI is planning to send a request for these data to the license holders this year.

Conclusions

A large variety of methods for the assessment of patient doses and frequency of x-ray examinations has been performed in Sweden during the last 30 years. Experience has been gained about the pros and cons of either approach, among other things on practical difficulties in the conduct of e.g. measurements in the field, on specification of examinations, on the reliability of data received in a questionnaire and on the accuracy or inaccuracy that is associated with either method. It is generally true that the need of resources is increasing with the demands on the accuracy of dose and frequency assessments. Another important issue is how to allocate the various tasks to various personnel in the clinic (depending on the competence available there) and to outside staff (e.g. authorities, research institutes).

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8. LUXEMBOURG POPULATION DOSE FROM MEDICAL X-RAYS

Ferid Shannoun

Introduction

The introduction of the European Directive 97/43 EURATOM [1] obliged each member state to implement it in national regulation. In the Grand Duchy of Luxembourg the Directive was implemented through the ordinance of March 16th 2001 [2]. This ordinance regulates the measures towards the radiation protection of patients, as well as the responsibilities of our department to evaluate the radiation exposure to the population from the use of ionizing radiation in medicine. A nation-wide evaluation on radiation doses from diagnostic procedures was conducted for the period 1994 - 2002 aiming at the estimation of the annual collective dose per caput. This work provided valuable data on the situation of diagnostic radiology in Luxembourg and it shows the increased impact of computed tomography (CT) to dose received from medical use of radiation.

Material and Methods

The study consisted of the health insurance data acquired for more than 425 000 patients in nine years (1994-2002). Regarding frequency aspects, the radiological examinations were grouped in the following main categories: computed tomography, conventional X-rays and interventional radiography. Patients receiving radiotherapy treatment were excluded from the survey. The patient’s identity remained anonymous. Each patient was identified by a specific study-ID, their year of birth and gender. In order to obtain detailed information about the age distribution and sex of the patients, the results were grouped in age classes of five years for both sexes. Concerning the dosimetric aspects, information regarding the effective dose per examination was taken from recent published studies. The collective dose was determined from information about the frequency and the mean effective dose for each examination. Demographic data of Luxembourg over the study time were used to standardise the results to 1 000 inhabitants.

Results

More than 5 million radiodiagnostic examinations were performed between 1994 and 2002 in Luxembourg. The study has shown that the total radiological examination frequency has been fairly constant during the study period with a yearly average of 1 300 exam (including dental) per 1 000 population. Figure 1 shows that dentists conducted on average 150 000 examinations per year (360/1 000 inhabitants).

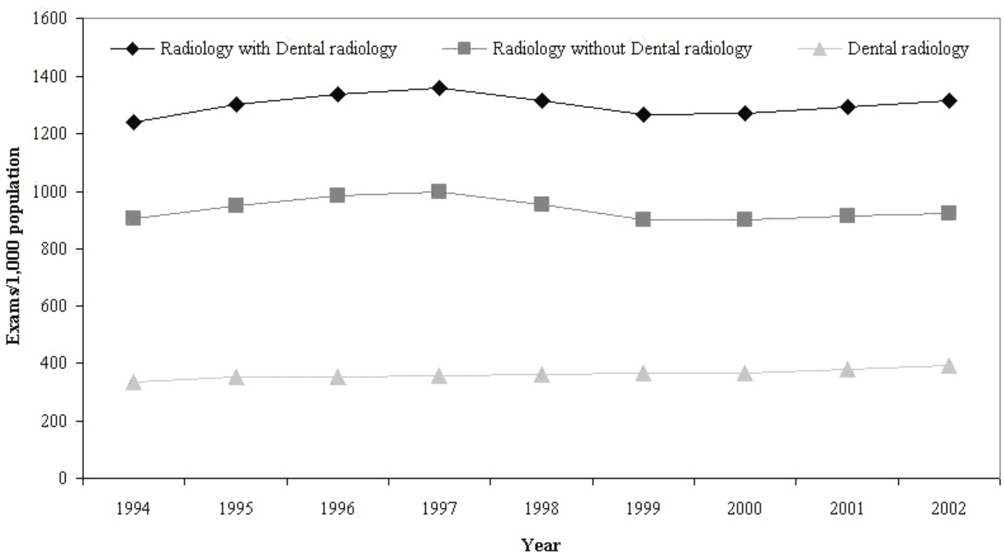

Figure 1. Annual frequency rate of diagnostic and dental radiology procedures.

The number of CT examinations has substantially increased. While there were 75 examinations per 1000 inhabitants in 1994, by 2002 the examination rate was recorded to 135/1 000 inhabitants, representing an increase of 80%. The frequency of interventional radiological examinations has been almost doubled in nine years. In 2002 about 4 000 interventional procedures were carried out (9/1 000 inhabitants). The analyses of distribution of the different examination procedures according to the irradiated body regions revealed no conspicuous results with the exception of intravenous urography. This examination is still carried out relatively frequently in Luxembourg (10/1 000 inhabitants). The frequency of mammographies has increased regularly since the start of the national mammography-screening program in 1992. Today more than 52% of all mammographies (annually about 13 000 exams) are done by the national screening program [3].
The sum of the products of examination frequencies and the average effective dose per examination yields the collective dose from diagnostic procedures. The collective dose from medical diagnostic X-rays procedures has continuously increased from 566 man-Sv in 1994 to 786 man-Sv in 2002. In parallel the average effective dose per caput has steadily increased from 1.47 mSv to 1.83 mSv for the same time period. The contribution of computed tomography has risen from 0.48 mSv to 0.99 mSv for the same period. In 2002 CT contributed about 54% to the medical collective effective dose from diagnostic radiology – nuclear medicine procedures not included –. The contributions from conventional radiology included fluoroscopy (RX) and interventional radiology (IR) were amounted to 39% and 7% respectively as demonstrated in Figure 2. The contribution of dental radiology (DR) was less than 1% to the collective dose over the nine years, which corresponds well to the average value of health care level I countries [4].

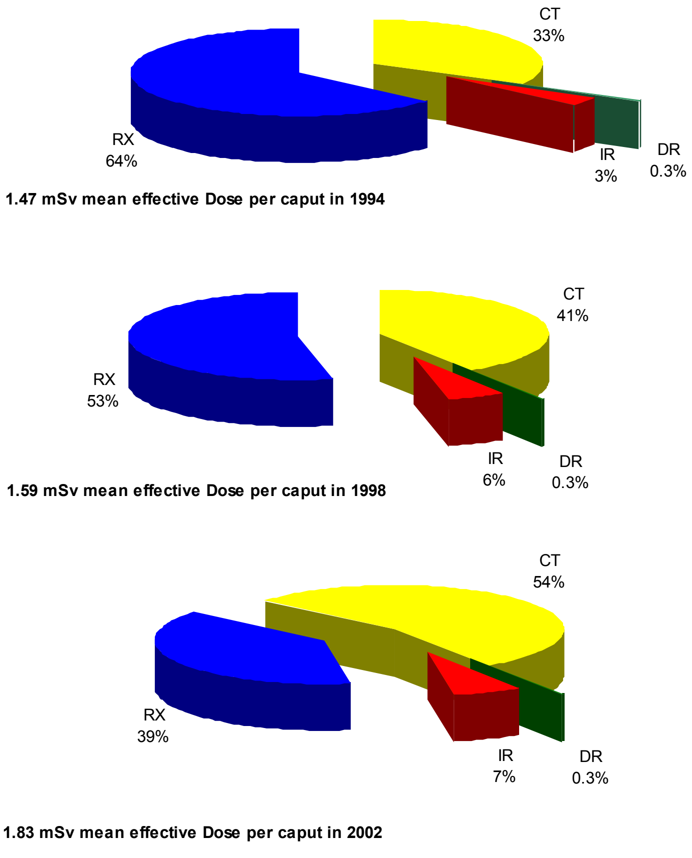

Figure 2: Contribution to the collective effective dose according to the main examination categories

Table 1 shows the percentage distribution for the main categories of diagnostic procedures broken down by the age of patients. The analysis of the patient's age and gender distribution showed no different profiles according to CT-examinations or conventional radiology procedures.
The distribution shows a relatively constant level for the ages 40 to 75 years for conventional x-rays examinations and computed tomography with a proportion of 7.8% and 8.6% respectively. More than 50% of all dental radiographs are performed in age between 20 and 45 years. The distribution of interventional procedures is shifted to older patients. About 80% of these interventions are done for patients between 50 and 80 years. Interventional procedures (cardiac or vascular) were significantly much more frequently obtained by men than women.
The international comparison of the average collective effective dose indicates that Luxembourg has a comparable level to Germany and Belgium and a clearly higher than the dose level reported by the Netherlands, Switzerland and the UK [5].

Table 1. Age distribution according to the main examination categories

Age (y)	Examination category			
	Dental (%)	X-rays (%)	CT (%)	Interven-tional (%)
0 – 4	0.1	1.8	0.4	0.1
5 – 9	2.4	2.2	0.7	0.1
10 – 14	5.5	3.7	1.0	0.1
15 – 19	6.7	3.8	2.0	0.2
20 – 24	8.4	4.0	3.0	0.3
25 – 29	10.7	5.0	4.7	0.5
30 – 34	11.9	6.2	6.7	1.0
35 – 39	11.3	7.0	8.1	1.8
40 – 44	9.6	7.7	8.8	3.7
45 – 49	8.0	8.1	9.2	6.2
50 – 54	6.6	8.7	9.0	8.5
55 – 59	5.4	7.8	8.2	10.7
60 – 64	4.5	7.4	7.9	13.5
65 – 69	3.7	7.6	8.8	16.5
70 – 74	2.6	7.0	8.5	17.1
75 – 79	1.4	5.3	6.4	12.0
80 – 84	0.7	3.5	3.9	5.5
85 – 89	0.3	2.2	2.1	2.2
90 – 94	0.1	0.7	0.6	0.6

Conclusion

Even though the use of ionising radiation for diagnostic medical procedures is an accepted part of modern medicine, the importance of keeping the patient dose as low as possible was clearly marked by the European Directive 97/43/EURATOM [1]. It appears that both the total number of CT examinations and the collective dose from CT has drastically increased since 1994. An effort should be made to reduce the patient dose from CT in Luxembourg through optimisation of the technical parameters and the examination protocols. It would be useful to establish dosimetric procedures for collecting all the measured doses to CT patients by using special software programs. All relevant information to make the estimation of the patient dose possible can be found in the DICOM header of the images and in the Radiological Information System (RIS). Medical physicists should be strongly involved to manage patient dosimetry in routine computed tomography. Medical practitioners are selecting the best possible investigation for each clinical stetting. The European referral criteria give a guide to the radiation caused by medical imaging and recommend investigation in various clinical settings [6]. These recommendations could play an important role in the optimisation process by avoiding unnecessary and unjustified examinations.

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9. BELGIAN POPULATION DOSE FROM MEDICAL X-RAYS

A. Lecluyse & L. Van Bladel

INTRODUCTION:

The first official survey of the radiological (X-ray) exposure of the patients/population in Belgium was done in 1998 (relating to 1996), by Hans Vanmarcke et al., by order of the Flemish Environmental Society (de Vlaamse Milieumaatschappij: VMM), with an important medical x-ray contribution by Harrie Mol. Since then the survey has been repeated every year and the results published in a background document on ionizing radiation (Achtergronddocument - Ioniserende straling) of the so called MIRA report (Milieu Rapport Vlaanderen) [1].

Moreover, in 2004, at the Federal Agency for Nuclear Control (FANC), which is the Belgian regulatory and controlling authority in matters concerning ionizing radiations and radioprotection, a working group was installed to fulfil the national obligations to UNSCEAR, in reporting about the medical exposures to ionizing radiations (in the domains of Radiology, Nuclear Medicine and Radiotherapy). Harrie Mol was one of the participants in this working group and provided much of the information on medical x-ray exposures for the period 1996 - 2002.

In 2005, in the framework of its national and international assignments, the FANC had fruitful consultations and deliberations with the 'Consilium Radiologicum' (representatives of the professional and scientific radiological societies) which resulted in a document, the so-called 'Vademecum' ("The use of X-rays for Medical Purposes" - August 2005) [2]. which has been published on our website (http://www.fanc.fgov.be) and distributed as a brochure to all the Belgian Radiologists and Medical Physics Experts (in the domain of Radiology). The purpose of publishing this document, and especially its Annex B on "Patient Dosimetry", was to clarify and explain to practitioners how the European guidelines on this matter would be implemented in Belgian legislation. According to this 'Vademecum' and its Annex B, enacted by Royal Decree (14 Sept, 2006) and published as directives in the Belgian Government Gazette/Belgian Official Journal (12 Oct, 2006), all Departments of Radiology must perform dose studies (in a 3 yearly cycle) including individual patient dose evaluations and registrations in interventional radiology, CT, pediatric radiology, etc.

FREQUENCY of X-RAY EXAMINATIONS

Frequency data for radiological examinations and/or procedures were obtained from the national institution for health and invalidity insurance (RIZIV/INAMI: Rijksinstituut voor Ziekte- en Invaliditeitsverzekering/Institut National d'Assurance Maladie Invalidité).

In Belgium this insurance is an obligation for all, and the RIZIV/INAMI reimburses, via the insurance organizations, the costs (up to a certain level) of the medical/radiological acts. A number of these acts will not be registered by the national insurance institution, for instance; acts performed on patients who are not insured, acts in the scope of occupational medicine, medico legal issues, scientific investigations, etc. However this number is not significant and contributes only about 1-3% to the total number, as was demonstrated by H. Mol, in two radiological departments of a university hospital (0.6% and 3.1%), and in a big private radiological department of a provincial town (0.2%).

The classification of the radiological acts used in drawing up the MIRA reports is based on the exposed anatomic regions (head and neck, thorax, abdomen, and limbs) taking into account the organs and exposures at risk (angiography, CT, interventional procedures), leading to 14 different groups. This was adapted from the classification used by UNSCEAR in its Medical Radiation Exposure Annex questionnaires. Some of the examinations specified by UNSCEAR are not easily retrievable from the RIZIV/INAMI nomenclature (~130 types of diagnostic examinations and/or interventional radiological procedures and ~53 categories), because they are not specifically registered and have no specific survey code. For instance, RIZIV/INAMI only takes 7 types of CT examination into account and does not make a distinction between CT Thorax and CT Abdomen.

As far as CT scanning is concerned; Belgium has one of the highest densities of CT scanners in Europe: 1 CT scanner/42,150 inhabitants. The total number of CT scanners in Belgium is about 242: 121 (50%) in the Flemish part, 85 (35%) in the French speaking part, and 36 (15%) in the Brussels' region. The number of new CT scanners installed per year is still increasing (~20 in 2000 & 2002, and ~30 in 2004 & 2005) and so is the number of CT examinations (1.17 million in 2000, 1.22 million in 2002, and ~1.4 million in 2004). 76% of the CT scanners in Belgium are less than 5 years old [3].

DOSES to the PATIENTS/POPULATION

Some dose data for patients were obtained from a study performed in 2000 by Mol and Van Loon [4] and first used in the MIRA report 2002. These were for only 6 types of examination: Chest/Thorax (PA, LAT), Lumbar Spine (AP, LAT, L5-S1, ¾), Abdomen (AP), IVU, CT Thorax and CT Abdomen. In this multi-centre dose study, phantom measurements with ionization chambers and/or measurements on 10 consecutive adult patients per examination were made in 17 Flemish radiological departments in 3 University Hospitals, 7 General/Regional hospitals, and 7 Private institutions/practices. The results shown in the Table below were extrapolated to the whole Belgian population assuming that medical practice in Flanders was similar to that in the Walloon provinces (the French speaking part of Belgium) and in the Brussels region. Thus the study and the global surveys, based on it, only give some rough estimation of the Belgian patient/population doses.

X-ray examination (no radioscopy)	**Skin dose** (mGy)	**Effective dose** (mSv) (calculated from phantom simulations)
Thorax AP	0,15 (0,08)*	0,025 (0,012)*
Thorax Lat	1,23 (0,86)	0,12 (0,09)
Lumbar Spine AP	6,1 (3,2)	0,69 (0,34)
Lumbar Spine Lat	10,5 (6,5)	0,28 (0,16)
Lumbosacral Spine Lat (L5-S1)	9,1 (7,2)	0,11 (0,07)
Lumbosacral Spine PA (L5-S1)	6,6 (3,3)	0,73 (0,33)
Lumbar Spine ¾	6,08 (3,2)	0,25 (0,13)
Abdomen AP	8,25 (13,2)	0,99 (1,56)
IVU		7,9
CT Abdomen		11,3 (7,88)
CT Thorax		4,14 (1,21)

* standard deviation in ()

In addition, a 2 year (2003-2005) multi-centre study has been done to investigate high-dose procedures (cardiac and coronary angiography, angiography of the lower limbs, cerebral angiography, and some frequent interventional procedures), sponsored by the FANC. The results in terms of DAP measurements and effective dose calculations (based on Monte Carlo), in 8 cardiology centres (cath labs) and in 12 interventional radiology centres were presented at a "Workshop on Interventional Radiology" organized by the FANC, the universities of Louvain, Ghent, Brussels (Flemish Free University), Liège and the SCK/CEN (Study Centre for Nuclear energy) at Mol, in Brussels on 25 March 2006.

Exam/procedure	Mean Effective dose (mSv)
Cardiac angiography	9.6
PTCA	15.3

Also a multi-centre study (27 centres in the Flemish part of Belgium, minimum 50 patients) was done, from December 2001 till March 2002 on doses from screening mammography with 4 images per patient [5]. The mean glandular dose was 1,67 mGy (1,54 mGy for a breast thickness class from 48 to 58 mm), with a standard deviation of 0,44 mGy. On a phantom the dose was 15% less than the mean patient dose.

In the MIRA report 2005 [1], CT scanning was responsible for 53% of the dose from radiological examinations. The technical evolution, with introduction of multi-detector row CT scanners, had an obvious impact on the increase of the dose per examination. However using low dose protocols can significantly reduce the total effective radiation dose. 70% of the CT examinations are performed on patients >45 years old [3].

However, most of the dose data in the surveys discussed in the MIRA reports [1] are gathered from the literature (e.g. from the Medical Radiation Exposure Annex of the UNSCEAR 2000 Report). In the surveys, data about dental x-ray examinations were not considered, because they result in only low doses.

Users of medical x-rays

In Belgium every medical doctor can perform radiological acts in his domain of specialization. So a general practitioner can take radiographs of the chest and the extremities, a cardiologist can make a chest X-ray, implant cardiac pacemaker electrodes under radioscopic guidance, and perform some other interventional radiological procedures (coronarographies, PTCAs, electrophysiological examinations, …), a pneumologist can take radiographs of the lungs, a gastroenterologist can do interventional radiological acts (e.g. ERCPs), a gynecologist can make hysterosalpingographies and pelvimetries, an abdominal surgeon can perform intra-operational cholangio-/cholecystographies, a vascular surgeon can make aorto-, arterio-, phlebo-, and lympho- angiographies, intra-operative control angiographies, or perform some interventional procedures (PTAs), an orthopaedic surgeon can do some orthopaedic/traumatological operations under radiological guidance, etc. Of course the domain of a radiologist covers all the radiological acts.

Nevertheless, no medical doctor can use X-rays unless he/she is licensed by the FANC (or the Ministry of Health, before September 1st 2001). At this moment he/she gets the licence to use X-rays for a 10 year period and has to pay a retribution at the beginning and on the occasion of the renewal of his licence (conditioned by proof of continued education in radiation protection). Licences are only granted to those who can prove having successfully followed a course of radiation protection at university level (75 hours: 40 theoretical lessons, 35 hours of practice). Such courses are integrated in the specialist training for radiologists, but are open to other medical trainees and practitioners as well.

Radiological acts can only be performed by a nurse or a technologist if these are delegated to this person by a medical doctor licensed for the use of X-rays, according to his/her instructions, and under his/her real control and responsibility. The nurse or technologist must have successfully followed a course in radiation protection (minimum 50 hours, and of these at least 15 hours of practice). Since 1998, courses are organized for people who want to get the diploma of Bachelor in Medical imaging or Radiographer (duration of the training: 3 years).

A dentist (master of dental sciences) however is not allowed to delegate dental radiography to either a nurse or technologist. He/she may only delegate if he/she is also a medical doctor or stomatologist (medical specialist).

CONCLUSIONS

In recent years Belgium has put quite some effort in further implementing the European Directives on radiological protection and in fulfilling its international obligations related to patient dosimetry in radiological procedures. We realize that we are only in the starting phase of this challenging project and that we still have a long way to go, for instance in the development of a national dose monitoring system.

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10. DANISH POPULATION DOSE FROM MEDICAL X-RAYS

Peter Gron

Purpose
Article 12 in Council Directive 43/97/Euratom of 30 June 1997 on health protection of individuals against the dangers of ionizing radiation in relation to medical exposure says that the Member States shall ensure that the distribution of individual dose estimates from medical exposure is determined.

This project was launched to determine the collective dose to the population in Denmark in the late nineties as it is required in the directive above.

Pilot study
To ensure that the measuring principles and protocol was correct a pilot study was set up. The pilot study should show if there was any weakness according to measuring equipment, methods, selection of examination and hospitals. This pilot study was made in the summer of 1995 and lasted for 7 weeks. From this pilot study it was concluded that 12 x-ray examinations contributed with more than 80 percent of the total collective dose. In the pilot study doses from 118 different examinations types where measured and the rest was taken from different kinds of literature.

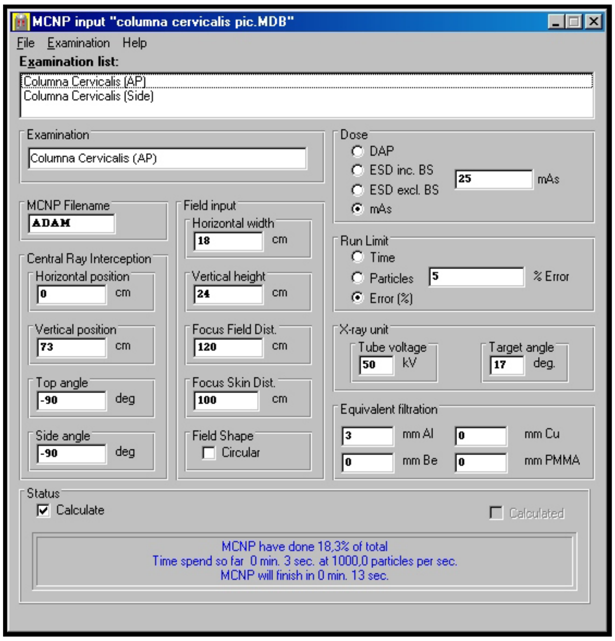
Dose measurements
The measurements was done by use of DAP meters and they where all calibrated at the institute before use. The institute had one radiographers travelling round in Denmark making the measurements. The measurements took almost two years and a lot of data was collected. The following parameters were noted as it was needed in the dose calculation.

- ◊ DAP value
- ◊ Focus Film Distance (FFD) and Focus Skin Distance (FSD)
- ◊ Voltage (kV)
- ◊ Field size
- ◊ Projection coordinates
- ◊ Patient data (age, weight, height, sex etc.).

Data was collected from more than 3.000 patients and data for more than 20.000 exposures was saved in the database developed for the project.

Dose calculation
The doses where calculated from the data stored in the database and the software used where the program *Diagnostic Dose* developed at the institute (see figure 1 below). The program uses the MCNP code and the ADAM mathematical phantom. The program where designed in such a way that the dose calculation could be performed on several computers on the same time. Normally this calculation where done during the night, otherwise the calculation would slow down the computers. For each exposure there where also generated a picture showing the projection on the patient.

Figure 1 *Input screen for the Diagnostic Dose Program*



The calculation of doses from CT where done by the program *CT Dose*. This program is freeware and is developed at the institute. I will not go into detail with the construction of the two programs, but just mention at both the program has the capability of calculating both effective dose and the different organ doses.

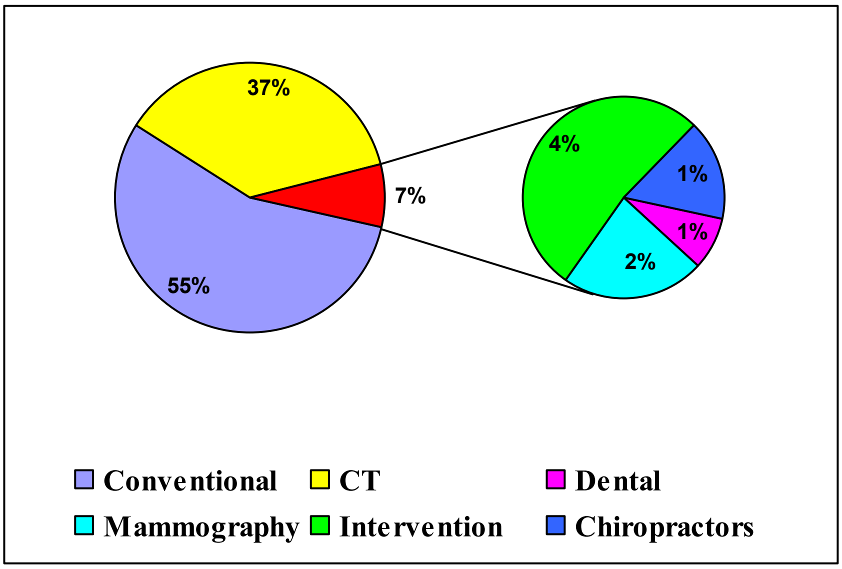
The measurements from chiropractors and dentist where done by use of TLD and solid state detectors and the doses where calculated by means of *Diagnostic Dose*. For mammography the effective dose where calculated from AGD (Average Glandular Dose) and ICRP publication no. 60.

Results

The total dose to the Danish public from diagnostic radiology can be found by adding the contribution from the different kind of practices (dental, conventional radiology, CT, chiropractors, mammography, and intervention). The results are shown in the table below. From the table it is clear that the largest contributes comes from the conventional radiology. CT contributes with almost 40 percent of the total dose, but the number of CT examinations is very small, only about 5 percent.

Area of radiology	Collective dose (manSv)	Dose pr. caput[2] (μSv)
Conventional radiology	1331	256
Intervention	95	18
Computer Tomography (CT)	901	173
Chiropractors	29	5,6
Mammography	40	7,6
Dental radiology	15	2,9
Total	2411	463

[2] Dose pr. caput is calculated 5.2 million inhabitants.



37%
7%
55%
4%
1%
1%
2%
Conventional
CT
Dental
Mammography
Intervention
Chiropractors

APPENDIX 2

ACCURACY OF POPULATION DOSE ESTIMATES

Population dose estimates are based on information regarding the frequency of x-ray examinations and typical patient doses, which is obtained from surveys of radiology practice in a country that are prone to many potential sources of systematic and random (or statistical) error. These sources of error lead to uncertainties in the frequency and dose estimates, and it is desirable, although often quite difficult, to identify, evaluate and combine the uncertainties associated with all major sources of error to obtain a measure of the overall uncertainty in the population dose estimate.

Systematic errors, also called bias, lead to estimates being systematically too high or too low, and a particular source of error will always affect the result in the same direction. All observations or measurements of x-ray examination frequency and patient dose are prone to systematic errors. They may, for example, be due to insufficient knowledge (or even a complete lack of knowledge) regarding the frequency of a particular specific type of x-ray examination, in which case assumptions have to be made regarding the relationship between the frequency of the desired examination and that of other examinations for which frequency data are available. It is likely that these assumptions will not be completely valid and the estimated frequency will consequently be biased. It is not possible to estimate the size or direction of the bias, but it is usually possible at least to make a rough evaluation of the maximum likely uncertainty in the estimated frequency due to the assumption made. This maximum uncertainty will be equally distributed on either side of the estimated value, but the shape of the distribution will not usually be known.

Random errors are due to statistical fluctuations which occur when observations or measurements are repeated under identical conditions. They are equally likely to be positive or negative about the true value and usually follow a normal distribution. Random or statistical errors arise, for example, from precision limitations in patient dose measurement devices and from surveys where frequency or dose data is collected from a sample of hospitals. Random errors can be reduced by averaging over a large number of observations.

To obtain an estimate of the accuracy of a population dose estimate (i.e. how close the estimated value lies to the true value) all major sources of uncertainty need to be identified, quantified and then combined in a standard way to determine the overall uncertainty. International guidance on the assessment and expression of uncertainties in measurements [e.g. ISO 1993, Guide to Expression of Uncertainty in Measurement] recognises that there are basically two ways to estimate uncertainties depending on whether they can be evaluated by statistical analysis of a series of observations made under identical conditions (Type A) or not, when other information has to be relied upon such as observations under similar but not identical conditions, or past experience, or even common sense (Type B). Type A evaluations would appear to be associated with 'random' errors and Type B with 'systematic' errors, but this is not necessarily the case. However, for each type of evaluation (A and B) the uncertainties can be quantified in a standard manner that allows them to be combined to assess the overall uncertainty.

For Type A uncertainties, which relate to the repeatability of a series of *m* observations made under identical conditions, the standard uncertainty (U_s) of the mean is given by the standard deviation, *s*, divided by $\sqrt{m}$

$$U_s = s/\sqrt{m}$$

where s is defined as the square root of the variance or the square root of the mean square deviations of the values N_y, from their arithmetic mean, $\overline{N}$

i.e. $$s = \sqrt{\frac{\sum_{y=1}^{m} \left(N_y - \overline{N}\right)^2}{m-1}}$$ and $$\overline{N} = \frac{\sum_{y=1}^{m} N_y}{m}$$

For type B uncertainties, it is usually possible to make an evaluation of the maximum likely uncertainty in the estimated value. This maximum uncertainty is equally distributed on either side of the estimated value, but the shape of the distribution will not usually be known. If there is no specific knowledge about the likely shape of the distribution, it is reasonable to assume a rectangular distribution with equal probability for the true value to lie anywhere within the range of the estimated maximum uncertainty. If 2a is the difference between the bounds of the maximum likely uncertainty, the standard uncertainty is given by the semi-range of the maximum uncertainty divided by $\sqrt{3}$

$$U_s = a/\sqrt{3}$$

If a number of different sources of random or systematic error are present, it might be that errors affecting the result in one direction are counterbalanced by other errors affecting the results in the other direction. The standard uncertainties associated with different sources of error are consequently combined to estimate the overall standard uncertainty using the established method of *propagation of uncertainty*.

Assuming the sources of error to be independent (not correlated), the overall standard uncertainty ΔN, of the quantity N which is a function of other quantities $n_1, n_2 \ldots . n_x$, is given by

$$\Delta N = \Delta N(n_1, \ldots, n_x, \Delta n_1, \ldots, \Delta n_x) = \sqrt{\sum_{i=1}^{x} \left(\frac{\partial N}{\partial n_i} \Delta n_i\right)^2}$$

where Δn_j is the uncertainty of n_j and $\frac{\partial N}{\partial n_i}$ is the partial derivative of N with respect to n_i.

If the quantity of interest, N, is made up of a sum, $N = \sum_{i=1}^{x} n_i$, the above formula is reduced to

$$\Delta N = \sqrt{\sum_{i=1}^{x} \Delta n_i^{\ 2}}$$

i.e. ΔN is the root mean square sum of the absolute uncertainties.

If N is made up of a product, $N = \prod_{i=1}^{x} n_i$, the above given formula is reduced to

$$\Delta N = \prod_{i=1}^{x} n_i \cdot \sqrt{\sum_{i=1}^{x} \left(\frac{\Delta n_i}{n_i}\right)^2}$$

i.e. the relative uncertainty, $\Delta N/N$, is the root mean square sum of the relative uncertainties.

In accordance with the Central Limit Theorem, the combined standard uncertainty takes the form of a normal distribution and there is a 68% confidence that the estimated value lies within the stated limits. In accordance with international practice, uncertainties will be expressed in this report in terms of the 95% confidence limits, which correspond approximately to twice the standard uncertainties (referred to in ISO, 1993 as a coverage factor of 2).

A2.1 Accuracy of frequency estimates

Essentially, two methods have been used for deriving x-ray examination frequency data in the DOSE DATAMED countries. Either annual numbers have been obtained directly from a sample of hospitals and/or practices or they are obtained from health insurance data bases covering a large proportion of national practice. In some countries, frequency data have been derived from both (e.g. Germany). Table 3 of basic data for the national surveys recently conducted in 10 European countries, shows that some countries had sample sizes close to 100% (usually based on comprehensive national health insurance statistics) whereas others had to rely on limited surveys restricted to <20% of the total national practice. Different algorithms are used to calculate the total national frequencies from the sample survey or the health insurance data. Uncertainties will be introduced in the calculation at each step that involves an assumption about the true distribution of the frequency data (scaling, extrapolation etc.).

In all DOSE DATAMED countries except the UK, predefined code systems are used to describe all the types of x-ray examination that take place. The code systems are mostly designed to meet national systems for reimbursement and are not ideally suited for counting the number of x-ray examinations. Thus the accuracy of the frequency data also depends on how reliably the coded information stored in hospital Radiology Information Systems (RIS's) or held centrally in health insurance databases can be translated into actual numbers of examinations.

The important sources of uncertainty in the estimates of x-ray examination frequency include:

1. Errors in relating the information stored in terms of examination codes into actual numbers of examinations
2. Bias in the sample and inaccuracies in the scaling factors used to derive frequencies for the whole country
3. Lack of frequency data from some important providers of radiology services.

A2.1.1 Errors in deriving numbers of examinations from the coding systems

A radiological examination may consist of several radiographs and/or the use of fluoroscopy, or several CT scans with or without intravenous contrast. Several organs or body parts might be involved in one examination depending on the clinical indication. In order to compare x-ray examination frequency data between countries (and to assign dose values to examinations), it is crucial that what constitutes "one x-ray examination" is defined and counted in a consistent way.

All DOSE DATAMED countries appear to have defined an x-ray examination in a similar manner, as follows:
'An x-ray examination or procedure is defined as one or more (a series of) x-ray exposures of one anatomical region/organ/organ system using a single imaging modality, needed to answer a specific diagnostic problem or clinical question during one visit to the radiology department or medical practice'.
For example, an examination of the GI tract involving a number of radiographs and fluoroscopy performed during the same visit, is considered to be ***one*** examination,

whereas a AP abdominal radiograph followed by a CT scan of the abdomen during one visit counts as ***two*** examinations.

According to this definition there will be a very large number of different types of x-ray examination carried out in each country. The first problem in comparing the frequency of x-ray examinations between countries is to draw up a common and unambiguous list of all specific types of examination that are performed. A list of 225 specific examination types was developed to cover all significant types of x-ray examination performed in the ten countries studies in this project. This list is shown in the third column of Table A2.1 and has been split into four parts –

Table A2.1(a)	Radiography
Table A2.1(b)	Fluoroscopy (excluding interventional procedures)
Table A2.1(c)	Interventional procedures
Table A2.1(d)	CT Examinations.

However, the various code systems are known to introduce possible mismatches between the number of times a code is recorded and the number of 'x-ray examinations', as defined above, that take place. Problems arise from either too little or too much detail in the code systems. For example, in Belgium there are only five codes to cover all types of CT examination whereas there are 30 codes covering examinations of the limbs and joints. In Germany, a clear allocation of codes to certain x-ray diagnostic procedures or to certain body regions or organ systems is not always possible since in certain cases the same code is used for different x-ray applications or various body regions. For example, one single "accumulative code" refers to all x-ray examinations of 'the extremities, the shoulder and the pelvis'. On the other hand, in the Norwegian system one examination can generate several examination codes and thorough analyses and adjustment of the reported codes is important in order to avoid over-counting the actual number of examinations. Counting examinations of double-sided organs (e.g. mammography and hip radiography) presents difficulties, unless the coding system clearly distinguishes between examinations involving just one side and both sides.

It is often the case that because of these limitations in the coding systems, frequency data can only be obtained for groups of examinations rather than for all the 225 specific examination types. Since there is currently no harmonisation of radiological code systems between European countries, the number of specific examination types or groups of examinations for which frequency data are readily available varies considerably from country to country. Table A2.1 lists all 225 specific examination types (third column) and shows in the second column (headed 'Exam category') how the specific examination types were most commonly grouped together in the different code systems used in the ten DOSE DATAMED countries. Generally speaking, only Germany, Netherlands and Sweden had serious problems in obtaining frequency data down to this level of aggregation (with a total number of about 70 examination categories covering all radiographic, fluoroscopic, interventional and CT procedures).

Table A2.1(a): RADIOGRAPHY

Region of body	Exam category	Specific exam types
Head	Skull & facial bones	Skull - Orbits - Temporal bones - petrous bone - mastoids - Sphenoid bone - sella turcica - sphenoid fissures Facial bones - Nose - Sinuses - Zygomas - Temporo-mandibular joint - Cervico-occipital hinge - Maxilla - Mandible - Cephalometry
	Head - soft tissue	Dacryocystography (tear ducts) Sialography (salivary glands) Eyes/orbits
Neck	Cervical spine	Cervical spine
	Neck - soft tissue	Larynx Pharynx Trachea
Chest/Thorax	Thoracic spine	Thoracic spine
	Shoulder girdle	Shoulder blades/ scapulae Collar bone(s) / clavicle(s) Acromio-clavicular joint Sterno-clavicular joint Manubrio-sternal joint Sternum
	Ribs	Ribs
	Chest/thorax/lung	Lung Thoracic inlet Bronchography
Abdomen	Lumbar spine	Lumbar spine
	Lumbo-sacral joint only	Lumbo-sacral joint
	Abdomen	Abdomen (plain film, patient supine or erect)
Pelvis	Pelvic bone	Pelvic bones - Ilium/ischium/pubis - Sacrum - Sacro-iliac joints - Coccyx
	Hips	1 or both hips
	Pelvis (soft tissue)	Pelvis (soft tissue)
Limbs (and joints)	Upper arm	Upper arm (humerus)
	Elbow	Elbow
	Forearm, wrist & hand	Forearm (radius & ulna) Wrist (scaphoid) Hand - Fingers & thumbs
	Femur	Femur

Region of body	Exam category	Specific exam types
	Knee	Knee Knee cap (patella)
	Lower leg, ankle & foot	Lower leg (tibia & fibula) Ankle Foot Calcaneum (heel) Toes
	Leg length	Whole leg
Trunk	Whole spine	Scoliosis
Head & trunk	Skeletal survey	Whole skeleton
Teeth & gums	Intra-oral <3 films	1-2 periapical films 1-2 bitewing fims 1 occlusal film
	Intra-oral >2 films	>2 periapical films Periapical full mouth survey >2 bitewing films
	Panoramic	Panoramic full mouth scan
Breast	Mammography	Symptomatic: - 1 or 2 views of 1 or both breasts Screening: - 1 or 2 views of 1 or both breasts

Table A2.1(b): FLUOROSCOPY (excluding interventional procedures)

Region of body	Exam category	Specific exam types
GI tract Neck + chest + abdomen	Oesophagus, stomach & small intestine	Oesophagus (Ba swallow) Stomach & duodenum (Ba meal) Small intestine (Ba follow) Enteroclysis (small intestine enema)
	Colon	Colon (Ba enema)
	Defecography	Defecography
Biliary tract	Biliary tract	Retrograde cholangiography Operative cholangiography Intravenous cholangiography T drain cholangiography Transhepatic cholangiography Endoscopic retrograde cholangio-pancreatography (ERCP) Retrograde pancreatography Cholecystography
Uro-genital tract	IVU	Intravenous urography (IVU)
	Kidneys & ureters	Retrograde pyelography Nephrostography
	Bladder & urethra	Retrograde cystography Micturitional cysto-urethrography (MCU) Urethrography
	Gynaecological	Hysterosalpingography
Spinal cord	Myelography	Cervical myelography Thoracic myelography Lumbar myelography Sacral myelography Whole spine myelography
Joints	Arthrography	Temporal-mandibular joint arthrography Shoulder arthrography Hip arthrography Elbow arthrography Wrist arthrography Knee arthrography Ankle arthrography

Region of body	Exam category	Specific exam types
Angiography	Cerebral angiography	Cerebral angiography Petrous phlebography
	Cardiac angiography (angiocardiography)	Coronary angiography (CA) - coronary arteries only - coronary arts. + L ventricle - coronary arts. + L ventricle + aorta Thoracic aortography
	Thoracic angiography	Bronchial arteriography Pulmonary arteriography Upper venacavography
	Abdominal angiography	Abdominal aortography Renal arteriography Mesenteric arteriography Lower venacavography Renal phlebography Suprarenal phlebography
	Pelvic angiography	Pelvic arteriography Ovarian phlebography Spermatic phlebography
	Peripheral angiography	Upper limb arteriography Lower limb arteriography Upper limb phlebography Lower limb phlebography
Lymphangiography	Lymphangiography	Thoracic lymphangiography Abdominal lymphangiography Pelvic lymphangiography Upper limb lymphangiography Lower limb lymphangiography

Table A2.1(c): INTERVENTIONAL RADIOLOGY

Region of the body	Procedure category	Specific procedure types
Head & neck	Cerebral interventions	Cerebral dilatation/stenting Cerebral embolisation (AVM, aneurysm, tumor) Cerebral thrombolysis Head & neck puncture
Chest	PTCA	Coronary dilatation/stenting (PTCA)
	Pacemaker	Cardiac pacemaker fitting (temporary or permanent)
	Hickman line	Central venous line fitting
	Other thoracic interventions	Cardiac thermo-ablation Valvuloplasty IVC (caval) filter fitting Oesophagus dilatation/stenting Thoracic dilatation/stenting Thoracic embolisation Thoracic thrombolysis Thoracic region biopsy Electrophysiology
Abdomen	Biliary & urinary systems	Bile duct dilatation/stenting Bile duct drainage Bile duct stone extraction Renal artery dilatation/stenting Renal drainage Lithotripsy Nephrostomy
	TIPS	TIPS (liver)
	Abdominal interventions	Abdominal dilatation/stenting Abdominal embolisation Abdominal thrombolysis Abdominal region biopsy
Pelvis	Pelvic interventions	Pelvic vessel dilatation Pelvic vessel embolisation Pelvic vessel thrombolysis
Limbs	Limb interventions	Upper limb dilatation Upper limb embolisation Upper limb thrombolysis Popliteal dilatation (behind knee) Lower limb dilatation Lower limb embolisation Lower limb thrombolysis Limbs biopsy

Table A2.1(d): CT EXAMINATIONS

Region of body	Exam category	Specific exam types
Head	Skull & facial bones	Skull - Orbits - Temporal bone - petrous bone - Temporal-mandibular joint - Sella turcica Face Dental
	Brain	Brain - Cerebrum - Posterior fossa - Brain vascular Pituitary gland
	Head soft tissues	Sinus Internal auditory meatus Nasal cavity Mouth
Neck	Cervical spine	Cervical spine
	Neck	Neck Larynx Pharynx Neck vascular
Chest	Thoracic spine	Thoracic spine
	Chest/thorax	Medastinum Lungs standard Lungs High Resolution Heart Thoracic aorta Lungs vascular
Abdomen	Lumbar spine	Lumbar spine
	Abdomen	Full abdomen Upper abdomen
	Liver, pancreas & kidneys	Liver / pancreas Kidneys / Supra-renal glands
Pelvis	Pelvic bones	Hip / pelvic bone Sacrum/coccyx Sacro-iliac joint
	Pelvimetry	Pelvimetry (obstetric)
	Pelvis	Pelvis (soft tissues/vascular)
Neck + chest + abdomen	Full spine	Full spine
Chest + abdomen	Chest & abdomen	Chest/abdomen
Abdomen + Pelvis	Abdomen & pelvis	Abdomen/pelvis
Chest + abdomen + pelvis	Chest, abdomen & pelvis	Whole trunk
Limbs	Limbs	Shoulder Elbow Wrist Hand Leg Thigh Knee Calcaneum Ankle Foot

A2.1.2 Bias in the sample and inaccuracies in the scaling factors used to derive frequencies for the whole country

If frequency data are derived from a relatively small sample of hospitals or practices, steps should be taken to ensure that the sample is as representative of national practice as possible. Ideally, all types of hospital and radiological practice should be included in the sample in similar proportions to those occurring nationally. When scaling up the numbers of each type of examination to the whole country, the assumption is made that the pattern of examinations seen in the sample is the same in the rest of the country. The statistical (random) errors involved in this assumption can be derived from the observed variations in the contribution of each examination category to the total between hospitals in the sample. This was done for the UK survey (see section A2.1.4). Also in the UK survey a rough estimate was made of the potential systematic errors (or bias) in the sample of hospitals included in the survey, by comparing the results from two geographically separated health regions (see section A2.1.4).

If frequency data are derived from health insurance data, and the data can be assumed to be complete, random errors should nevertheless be taken into account. One advantage of health insurance data is that it is usually provided regularly (e.g. annually) so that a time series of frequency data can be derived. If m is the number of data sets available, i.e. the number of points of time where frequency data were evaluated, then, the standard deviation, a measure of statistical dispersion, of the m frequency values, N_y, can be calculated. The standard deviation, s, is defined as the square root of the variance or the square root of the mean square deviations of the values N_y, from their arithmetic mean, $\overline{N}$:

$$s = \sqrt{\frac{\sum_{y=1}^{m}\left(N_y - \overline{N}\right)^2}{m-1}} \quad \text{where} \quad \overline{N} = \frac{\sum_{y=1}^{m} N_y}{m}$$

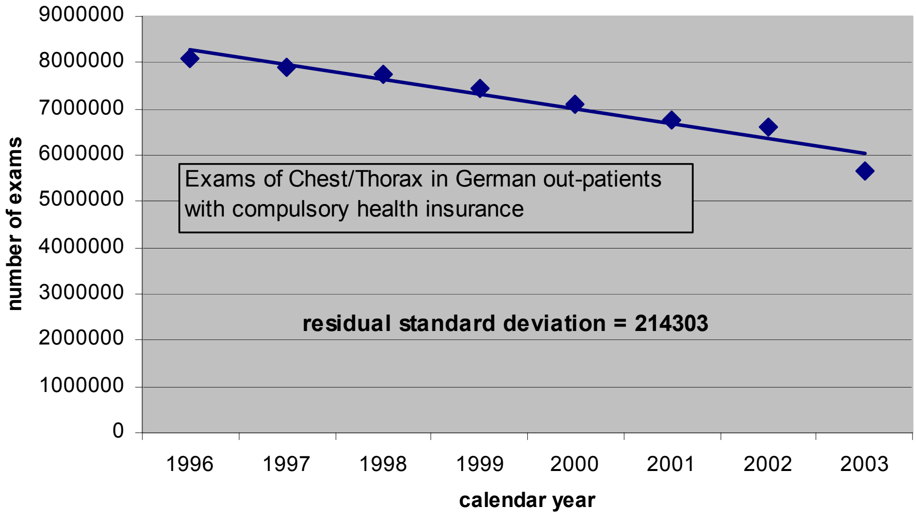
The standard deviation may serve as a measure of uncertainty. Therefore, assuming that systematic trends in the x-ray examination frequencies over a certain period of time are interpreted as random uncertainties, the uncertainties of N_y can be approximated by the standard deviation of the corresponding m frequencies, N_y. This would be a conservative approach. If the time series shows clear evidence of a trend, this can be accounted for via a regression analysis by using the "residual standard deviation", s_r, which can be written as

$$s_r = \sqrt{\frac{\sum_{y=1}^{m}\left(N_y - \tilde{N}_y\right)^2}{m-p}}$$

where $\tilde{N}_y$ is the value on the regression curve and p is the number of parameters in the regression function (e.g. p=2 in case of a linear regression).

This method can be applied to estimate the uncertainty both for the total frequency of all examinations together and for the frequencies of particular types or categories of examination (e.g. the Top 20 Exams). Germany, where frequency data for the years 1996 to 2003 (m = 8) were available, took this approach in its uncertainty analysis (see section A2.1.4).

To illustrate the method, an example is given for exams of the chest/thorax:



The figure gives the absolute number of chest exams for German out-patients with compulsory health insurance for the years 1996 to 2003. The line is the result of a linear regression analysis. Twice the value of the residual standard deviation is taken to approximate the uncertainty on frequency due to variance at the 95% confidence level (214303 x 2 = 428606 = 6% of the number of chest/thorax exams in 2000, as shown in Table A2.4 in section A2.1.4).

A2.1.3 Lack of frequency data from important providers of radiology services

The information in Table 2 on Healthcare Providers regarding their inclusion in national surveys can be used as a first step in assessing the completeness of the frequency data in each country.

Only Norway and Belgium had not included dental radiology conducted by dentists in 'Dental Practices' in their latest national surveys according to Table 2. This will have little impact on the collective dose but a big impact on the frequency of x-ray examinations, since dental x-rays exposure the patient to very low effective doses but account for about one third of all x-ray examinations in most countries. However, Norway has since made estimates for dental radiology to include in the Results section of Table 3.

The inclusion of 'School Dental Services', 'Health Checks at Borders', 'Prisons', 'TB Screening Units', 'Armed Forces Hospitals/Units' and 'Medical Research Exposures' in the national surveys varies from country to country. But this will have little impact on the completeness of the frequency data, since the contribution from these providers to the total frequency of x-ray examinations (and to the collective population dose) is insignificant.

Apart from the above exceptions, it would appear from Table 2 that all countries have included all significant healthcare providers in their national surveys, so their frequency data should be essentially complete.

However, in the Norwegian survey some angiography examinations conducted outside radiological departments might have been missed, which led to a relatively large uncertainty in the frequency estimate for these examinations.

A2.1.4 Overall uncertainty in frequency estimates

Many types and categories of examination make only a minimal contribution to the collective population dose, so in assessing the overall accuracy of the frequency data (and ultimately the accuracy of the population dose estimates) it was decided to give priority to the 'Top 20 Exams' that contribute 70-90% of the collective effective dose from all x-ray examinations in the DOSE DATAMED countries (see section 9.2 and Appendix 3).

The major problem lies in putting a value on the likely uncertainty associated with each step in the evaluation of the frequency for each of the Top 20 Exams. Examples of how this has been done in the UK, Norwegian and German surveys are shown in the following Tables A2.2, A2.3 and A2.4, respectively.

In the UK survey the uncertainties associated with the relatively small sample of hospitals from which the frequency of examinations was derived were quantified (see A2.1.2), and although ranging from 4.2% to 56.6% for individual Top 20 Exams, the uncertainty in the total frequency for all of them was less than 4%.

Table A2.2 Frequency uncertainties for Top 20 Exams in UK

		Uncertainties at the 95% confidence level			
Top 20 Exam	**UK annual frequencies 2001**	**Random error from A2.1.2* (%)**	**Systematic error from A2.1.2** (%)**	**Total % error on frequency**	**Total absolute uncertainty on frequency**
Cervical spine	833,099	4.2	0	4.2	34990
Thoracic spine	276,486	5.2	0	5.2	14377
Lumbar spine	896,000	11.8	0	11.8	105728
Pelvis & hip	1,773,111	6.1	0	6.1	108160
Chest	8,244,192	4.2	0	4.2	346256
Mammography	1,692,303	13.8	25	28.6	483253
Abdomen	1,212,900	5.0	15	15.8	191776
Ba meal	98,233	10.8	0	10.8	10609
Ba follow-through	34,531	10.4	0	10.4	3591
Ba enema	358,168	7.4	0	7.4	26504
IVU	161,929	12.0	27	29.5	47844
Cardiac angiography	163,000	45.2	0	45.2	73676
CT head	618,391	3.8	15	15.5	95689
CT neck	24,332	12.0	40	41.8	10161
CT abdomen	297,244	9.2	27	28.5	84787
CT chest	192,885	9.4	0	9.4	18131
CT pelvis	139,722	9.6	32	33.4	46680
CT spine	63,183	20.4	0	20.4	12889
CT trunk***	20,000	40.0	40	56.6	11314
PTCA	22,440	28.6	0	28.6	6418
Total for Top 20 Exams ****	*17,122,150*				*665093.27*
Total relative uncertainty					**3.9 %**

* 2 x standard errors in Table E1 of NRPB-R320

** 1/2 potential systematic error in Table E2 of NRPB-R320

*** CT trunk = CT angiography, CT interventional & CT other

**** *Total absolute uncertainties for Top 20 Exams = root mean square sum of the absolute uncertainties*

In the Norwegian survey where frequency data was obtained from every hospital in the country for 250 types of x-ray examination, sampling errors were very small. The major uncertainties were due to inadequacies in the coding system that led to the possibility of double-counting for some conventional examinations that involved 'double-sided' organs (e.g. hips and mammography) or for CT examinations that might or might not involve contrast. There were also large uncertainties associated with angiography examinations and PTCA where some of them that were conducted outside radiological departments might have been missed. However, the uncertainty in the total frequency for all Top 20 Exams in Norway remains very low at about 1.5%.

Table A2.3 Frequency uncertainties for Top 20 Exams in NORWAY

No.	Top 20 Exam	No of exams in NORWAY 2002	(95% confidence level) Uncertainty on frequency (%)	Absolute uncertainty on frequency
2	Cervical spine	92,542	2.5	2314
3	Thoracic spine	40,018	2.5	1000
4	Lumbar spine	161,058	2.5	4026
7	Pelvis & hip	340,969	5.0	17048
1	Chest	731,549	2.5	18289
5	Mammography	349,056	5.0	17453
6	Abdomen	46,056	2.5	1151
8	Ba meal	10,733	2.5	268
10	Ba follow-through	8,231	2.5	206
9	Ba enema	28,245	2.5	706
11	IVU	24,628	2.5	616
12	Cardiac angiography	17,530	20.0	3506
13	CT head	183,922	5.0	9196
14	CT neck	10,583	2.5	265
17	CT abdomen	81,279	5.0	4064
15	CT chest	49,631	5.0	2482
18	CT pelvis	52,053	5.0	2603
16	CT spine	76,871	2.5	1922
19	CT trunk	0	0.0	0
20	PTCA	2,513	20.0	503
	Total for Top 20 Exams	2,307,467		*32938.34*
	Total relative uncertainty			**1.4**

About uncertainty NORWEGIAN frequency data:	
Modality:	
Conventional exams, A	2.5 %
Conventional exams, B	5%
Angiography	20%
CT without contrast	2.50%
CT with/without contrast	5%

In the German survey uncertainties in the frequency estimates have been calculated separately for the two health insurance schemes for out-patients and for in-patients, and then combined together to obtain the total uncertainty for each Top 20 exam and for all Top 20 Exams together. The total uncertainty for each Top 20 Exam ranges from 9-57%, whereas that for all Top 20 Exams together is about 6%.

Table A2.4 Frequency Uncertainties for Top 20 Exams in GERMANY (95% confidence level)

Top 20 Exam	KBV (out-patients, compulsory health insurance)	uncertainty on frequency (%) due to variance	absolute uncertainty on frequency	PKV (out-patients, private health insurance)	uncertainty on frequency (%) due to variance	absolute uncertainty on frequency due to variance and due to scaling (20%)	In-patients	% uncertainty on frequency	absolute uncertainty on frequency
Chest/thorax	7,104,641	6%	426,278	831,397	12%	193,913	14,548,962	22%	3,200,772
Cervical spine	4,356,900	6%	261,414	326,005	15%	81,501	585,885	27%	158,189
Thoracic spine	1,728,312	8%	138,265	229,188	20%	64,824	450,373	30%	135,112
Lumbar spine	3,342,872	7%	234,001	442,857	18%	119,161	839,686	23%	193,128
Mammography	5,844,194	15%	876,629	629,230	17%	165,165	273,276	40%	109,311
Abdomen	904,289	2%	18,086	239,143	12%	55,777	1,984,558	24%	476,294
Pelvis & hip	5,161,981	2%	103,240	594,114	17%	155,948	1,776,259	25%	444,065
Ba meal	151,530	26%	39,398	14,991	80%	12,362	110,913	60%	66,548
Ba enema	50,469	7%	3,533	10,973	90%	10,117	148,034	55%	81,418
Ba follow	50,002	7%	3,500	3,478	100%	3,547	35,628	110%	39,191
IVU	900,933	3%	27,028	100,866	25%	32,293	231,337	45%	104,101
Cardiac angiography	329,662	4%	13,186	86,652	52%	48,277	886,313	58%	514,062
CT head	1,251,603			196,679			1,204,842		
CT neck	208,600			32,780			200,807		
CT chest	570,175			89,598			548,873		
CT spine	399,818			62,828			384,880		
CT abdomen	869,169			136,583			836,696		
CT pelvis	142,544			22,400			137,218		
CT trunk	34,767			5,463			33,468		
All CT	3,476,675	2%	69,533	546,331	3%	110,489	3,346,784	51%	1,706,860
PTCA	14,840	30%	4,452	1,740	125%	2,203	114,824	65%	74,635
Total Top 20	**33,417,300**		**1,053,909**	**4,056,966**		**364,980**	**25,332,831**		**3,737,398**
Total relative uncertainty			**3.2%**			**9.0%**			**14.8%**

Table A2.4 (cont) Frequency uncertainties for Top 20 Exams in Germany (95% confidence level)

Top 20 Exam	TOTAL Frequencies (KBV + PKV + In-patients)	TOTAL absolute uncertainty on frequency (without consideration of accumulative codes)	factor for accumulative codes	Uncertainty on frequency due to accumulative codes (%)	TOTAL absolute uncertainty on frequency	TOTAL relative uncertainty on frequency
Chest/thorax	22,485,000	3,234,850	100%	0%	3,234,850	14%
Cervical spine	5,268,790	316,233	40%	15%	800,377	15%
Thoracic spine	2,407,873	203,898	20%	15%	363,476	15%
Lumbar spine	4,625,416	325,966	40%	15%	705,958	15%
Mammography	6,746,701	898,725	100%	0%	898,725	13%
Abdomen	3,127,989	479,890	35%	10%	355,041	11%
Pelvis & hip	7,532,354	481,842	30%	10%	766,980	10%
Ba meal	277,434	78,317	100%	0%	78,317	28%
Ba enema	209,476	82,121	25%	40%	86,269	41%
Ba follow	89,107	39,506	50%	40%	40,751	46%
IVU	1,233,136	112,296	100%	0%	112,296	9%
Cardiac angiography	1,302,627	516,492	100%	0%	516,492	40%
CT head	2,653,124					
CT neck	442,187					
CT chest	1,208,646					
CT spine	847,526					
CT abdomen	1,842,447					
CT pelvis	302,161					
CT trunk	73,698					
All CT	7,369,790	1,711,845	100%	0%	1,711,845	23%
PTCA	131,404	74,800	100%	0%	74,800	57%
Total Top 20	**62,807,097**	**3,900,267**	**100%**	**0%**	**3,900,267***	**6.2%**

A2.2 Accuracy of patient dose estimates

Uncertainties occur at a number of points in the estimation of typical (mean) effective doses for x-ray examinations. Estimates of the typical effective dose for each type of examination in a country are usually based on measurements of 'application specific dose quantities' (see section 8) at a limited number of hospitals and conversion of these measurements to effective doses. The important sources of uncertainty in these estimates include:-

1. Uncertainties in the basic dose measurements.
2. Uncertainties due to variations in patient doses between hospitals and the limited sample size.
3. Uncertainties in the coefficients used to convert the measured dose quantities into typical effective doses.

A2.2.1 Uncertainties in basic dose measurements

ICRU Report 74 (ICRU, 2006) indicates that an uncertainty of no more than 7% at the 95% confidence level is required and, in general, achievable, for patient dose measurements in diagnostic radiology. However, careful attention to the calibration procedures and measurement methods described in ICRU Report 74 is necessary to achieve this level of accuracy. Since these may not always have been closely adhered to in the patient dose surveys discussed in this report, uncertainties of about ±10-20% are likely to apply to individual basic dose measurements, unless there is specific information to the contrary.

In general, these measurement uncertainties are small compared to the variation in dose seen in a sample of patients undergoing the same x-ray examination in the same hospital and compared to the variation in mean doses for the same x-ray examination between all hospitals in a national survey. Consequently, the uncertainties in the individual basic dose measurements will not have a significant impact on the accuracy of the average dose estimates that are used to calculate the mean effective doses associated with each type of x-ray examination. Essentially, the uncertainties due to the variation in measured patient doses between hospitals, as discussed in the next section, are taken to include the uncertainties in the dose measurements themselves.

A2.2.2 Uncertainties due to variation in patient doses between hospitals and limited sample size for patient dose survey

Estimates of the typical effective dose for each type of examination in a country are usually based on measurements at a limited number of hospitals. Doses can vary between radiology rooms in the same hospital, so the typical national value is usually based on the mean of the radiology room mean dose values from as representative a sample of rooms and hospitals as possible.

A method has been developed to roughly ascribe uncertainties due to the variation in patient doses between x-ray rooms and the limited number of rooms in any survey, based on the dose distributions observed in the UK National Patient Dose Database, which is one of the most extensive in all the DOSE DATAMED countries. These random uncertainties were derived from the standard errors on the mean (SEOM) of the radiology room mean dose values (SEOM = Standard Deviation / $\sqrt{n}$), which were seen to increase as the number of rooms (n) where measurements were made decreased. Approximate uncertainties at the 95% confidence limit are shown in the Table below, set at rounded values of twice the SEOM.

Sample size	SEOM (%)	95% Confidence Limit
> 100 rooms	4.4 (3.3-6.0)	±10%
20-100 rooms	13 (10-18)	±25%
5-19 rooms	23 (10-30)	±50%

The above random uncertainties do not take account of any systematic uncertainty due to potential bias in the sample of rooms chosen that makes them unrepresentative of national practice. Since it is very difficult to determine how representative a sample of rooms is of national practice, it is impossible to quantify this source of uncertainty, but it should be low if all reasonable steps have been taken to ensure as random a sample of hospitals and rooms as possible.

If no dose measurements have been performed in the country for a particular examination and the mean effective dose is taken to be the same as that observed in another country, the uncertainties may be larger. A general 95% confidence limit of a factor of 2 is suggested (+100%, -50%) unless there are good reasons to believe that radiology practice in the foreign country is similar to that in the country in question and the foreign data is based on measurements in >20 radiology rooms.

A2.2.3 Uncertainties in conversion coefficients

In addition to the above sources of uncertainty in the measured doses there are also systematic uncertainties associated with the conversion coefficients used to calculate effective dose. These are difficult to quantify and depend on how closely the exposure conditions and the phantom for which the conversion coefficients were calculated match the average exposure conditions and the average patient for the x-ray examination in question. The reference phantom used in the Monte Carlo calculations of the conversion coefficients closely matches the size of the average patient seen in all examinations in the UK National Patient Dose Database (except for cardiac examinations where the patients tend to be larger) [Hart et al, 2002]. For many of the common x-ray examinations, conversion coefficients have been calculated with exposure conditions closely matching the average used in clinical practice, so the uncertainties should be small with a 95% confidence limit of probably no more than about ±10%. For other less common examinations the match will not be so good and uncertainties could rise to about ±25%.

Overall uncertainty in patient dose estimates

The uncertainties associated with limitations in the size of the patient dose survey and with the coefficients used for converting measured doses into effective doses can be combined to estimate the overall uncertainty in the mean effective dose estimate for a particular examination using the standard method of propagation of uncertainties (i.e. the overall uncertainty is equal to the root mean square sum of the individual uncertainties).

Overall uncertainties estimated in this way for a number of different sample sizes and for good and poor matching of exposure conditions in the conversion coefficient calculations are shown in the last column of the Table below.

Sample size and matching of conversion coefficients	**Uncertainties at 95% confidence level (%)**		
	Sample size	**Conversion coefficient**	**Overall**
>100 rooms, good CC match	±10%	±10%	±14%
20-100 rooms, good CC match	±25%	±10%	±27%
5-19 rooms, good CC match	±50%	±10%	±51%
>100 rooms, poor CC match	±10%	±25%	±27%
20-100 rooms, poor CC match	±25%	±25%	±35%
5-19 rooms, poor CC match	±50%	±25%	±56%
Foreign data only			+100% - 50%

CC = Conversion coefficient

These overall uncertainties in mean effective doses estimates are used in the following section to calculate the accuracy of the collective effective dose estimates for the Top 20 Exams in the UK, Norwegian and German surveys.

A2.3 Accuracy of collective effective dose estimates

Firstly, the total uncertainty in the estimates of the frequency and the mean effective dose for each top 20 exam have to be combined to obtain the uncertainty in the collective dose for each examination. Since the collective dose for each examination is the product of the frequency and the mean effective dose, the uncertainties are combined by adding the *relative* risks in quadrature. The overall uncertainty in the collective dose for all top 20 exams combined is then obtained by simply adding the *absolute* risks for each examination in quadrature, according to the standard method of propagation of uncertainties. This has been done in the following spreadsheets for the UK, Norway and Germany (Tables A2.5, A2.6 and A2.7, respectively).

Table A2.5 Uncertainties in collective dose for Top 20 Exams in UK

Top 20 Exam	UK annual frequency in 2001	Total % error on frequency	Mean E (mSv)	Uncertainty on E (%)	Collective dose UK (man Sv)	Relative uncertainty on collective dose (%)	Absolute uncertainty on collective dose (man Sv)
Cervical spine	833,099	4.2	0.07	51	58.32	51.17	29.84
Thoracic spine	276,486	5.2	0.7	27	193.54	27.50	53.22
Lumbar spine	896,000	11.8	1.0	14	896.00	18.31	164.05
Pelvis & hip	1,773,111	6.1	0.5	14	886.56	15.27	135.39
Chest	8,244,192	4.2	0.02	14	164.88	14.62	24.10
Mammography	1,692,303	28.6	0.3	14	507.69	31.80	161.46
Abdomen	1,212,900	15.8	0.7	14	849.03	21.12	179.30
Ba meal	98,233	10.8	2.6	27	255.41	29.08	74.27
Ba follow-through	34,531	10.4	3	27	103.59	28.93	29.97
Ba enema	358,168	7.4	7.2	27	2578.81	28.00	721.96
IVU	161,929	29.5	2.4	27	388.63	40.02	155.55
Cardiac angiography	163,000	45.2	6.6	51	1075.80	68.15	733.13
CT head	618,391	15.5	2	14	1236.78	20.87	258.08
CT neck	24,332	41.8	2.5	14	60.83	44.05	26.79
CT abdomen	297,244	28.5	10	14	2972.44	31.77	944.49
CT chest	192,885	9.4	8	14	1543.08	16.86	260.21
CT pelvis	139,722	33.4	10	14	1397.22	36.22	506.13
CT spine	63,183	20.4	4	14	252.73	24.74	62.53
CT trunk	20,000	56.6	20	51	400.00	76.16	304.66
PTCA	22,440	28.6	15.1	51	338.40	58.47	197.87
Total	17,122,150				16159.74		*1617.47*
						Total relative uncertainty	**10.0 %**

Table A2.6 Uncertainties in collective dose for Top 20 Exams in NORWAY

Top 20 Exam	Annual frequency in 2002	Total % error on frequency	Mean E (mSv)	Uncertainty on E (%)	Collective dose (man Sv)	Relative uncertainty on collective dose (%)	Absolute uncertainty on collective dose (man Sv)
Cervical spine	92,542	2.5	0.20	51	18.51	51.06	9.45
Thoracic spine	40,018	2.5	0.7	27	28.01	27.12	7.60
Lumbar spine	161,058	2.5	1.4	14	225.48	14.22	32.07
Pelvis & hip	340,969	5.0	0.6	14	204.58	12.00	24.55
Chest	731,549	2.5	0.10	14	73.15	11.00	8.05
Mammography	349,056	5.0	0.1	14	34.91	14.87	5.19
Abdomen	46,056	2.5	3.6	14	165.80	14.22	23.58
Ba meal	10,733	2.5	5.1	27	54.74	27.12	14.84
Ba follow-through	8,231	2.5	2.2	27	18.11	27.12	4.91
Ba enema	28,245	2.5	12.5	27	353.06	27.12	95.73
IVU	24,628	2.5	3.8	27	93.59	27.12	25.38
Cardiac angiography	17,530	20.0	9.4	51	164.78	54.78	90.27
CT head	183,922	5.0	1.8	14	331.06	14.87	49.22
CT neck	10,583	2.5	3.4	14	35.98	14.22	5.12
CT abdomen	81,279	5.0	12.6	14	1024.12	14.87	152.25
CT chest	49,631	5.0	11.5	14	570.76	14.87	84.85
CT pelvis	52,053	5.0	9.3	14	484.09	14.87	71.97
CT spine	76,871	2.5	4.3	14	330.55	14.22	47.01
CT trunk****	0	0.0	0	1	0.00	1.00	0.00
PTCA	2,513	20.0	9.9	51	24.88	54.78	13.63
Total	2,307,467				4236.15		*247.04*
						Total relative uncertainty	**5.8%**

Table A2.7 Uncertainties in collective dose for Top 20 Exams in GERMANY

Top 20 Exam	Annual frequency in 2000	Total % error on frequency	Mean E (mSv)	Uncertainty on E (%)	Collective dose (man Sv)	Relative uncertainty on collective dose (%)	Absolute uncertainty on collective dose (man Sv)
Chest/thorax	22,485,000	14%	0,3	52%	6,745,500	54%	3,639,431
Cervical spine	5,268,790	15%	0,3	52%	1,580,637	54%	856,286
Thoracic spine	2,407,873	15%	0,5	52%	1,203,936	54%	651,892
Lumbar spine	4,625,416	15%	1,7	52%	7,863,207	54%	4,261,355
Mammography	6,746,701	13%	0,6	52%	4,048,020	54%	2,172,942
Abdomen	3,127,989	11%	1,3	52%	4,066,386	53%	2,164,308
Pelvis & hip	7,532,354	10%	0,7	52%	5,272,648	53%	2,793,848
Ba meal	277,434	28%	11,6	50%	3,218,235	57%	1,847,863
Ba enema	209,476	41%	15,9	50%	3,330,666	65%	2,157,504
Ba follow	89,107	46%	15,5	50%	1,381,164	68%	935,876
IVU	1,233,136	9%	3	50%	3,699,407	51%	1,880,132
Cardiac angiography	1,302,627	40%	10,4	50%	13,547,323	64%	8,644,981
CT head	2,653,124		2,6				
CT neck	442,187		2,5				
CT chest	1,208,646		7,7				
CT spine	847,526		2,9				
CT abdomen	1,842,447		18,6				
CT pelvis	302,161		10,6				
CT trunk	73,698		24,4				
All CT	7,369,790	23%	8,1	17%	59,695,299	29%	17,182,851
PTCA	131,404	57%	23	50%	3,022,291	76%	2,289,841
Total	62,807,097				118,674,720		20,579,243
						Total relative uncertainty	**17.3%**

The resulting estimates of the overall uncertainties at the 95% confidence level in the collective dose for the top 20 examinations in each of these countries is shown in the Table below. Each one has been rounded up by the percentage of the total collective dose from all examinations that is unaccounted for in the top 20 exams, to provide a rough estimate of the overall uncertainty in the collective dose from **all** examinations.

Country	**Overall uncertainty in collective dose from top 20 exams** (95% confidence level)	**% of total S from Top 20 exams**	**Overall uncertainty in collective dose from all x-ray exams** (95% confidence level)
UK	10%	82.3	12%
Norway	5.8%	86.4	7%
Germany	17%	85.3	20%

APPENDIX 3

TABLES SHOWING DETAILED FREQUENCY AND PATIENT DOSE RESULTS FOR THE 'TOP 20 EXAMS' IN EACH COUNTRY

Table A3.1: Top 20 Exams[0]

UK	2001

Exam 'type'	Specific exams included in 'Exam type'	No. exams /y/1000 pop	% of total freq [1]	S/y/ 1000 pop [mSv] [2]	% of total S [3]	Mean E per exam [4] (mSv)	Trend in Freq [5]
Radiography (plain film)							
1. Chest/thorax (lungs)	Lungs & ribs (chest/ribs) Thoracic inlet Bronchography	141	29.2	2.5	0.7	0.02	0
2. Cervical spine	Cervical spine	14	2.9	0.9	0.2	0.07	0
3. Thoracic spine	Thoracic spine	5	1.0	3.0	0.8	0.6	0
4. Lumbar spine (inc. LSJ)	Lumbar spine Lumbo-sacral joint (LSJ) Sacro-iliac joints Sacrum & coccyx	19	3.9	11.5	3.0	0.6	0
5. Mammography	Symptomatic & screening	27	5.6	8.6	2.3	0.3	+
6. Abdomen	Abdomen (plain film)	21	4.3	12.5	3.3	0.6	0
7. Pelvis & hip	Pelvis / Hip Orthopaedic pinning (incl hip)	31	6.4	14.3	3.8	0.5	0
Radiog/Fluoro							
8. Ba meal	Ba meal/stomach & duodenum	1.7	0.4	3.9	1.0	2.3	-
9. Ba enema	Ba enema/colon	6	1.2	39.7	10.4	6.6	0
10. Ba follow	Small intestine – Ba follow Small bowel enema	0.7	0.1	2.3	0.6	3.3	-
11. IVU	IVU	2.8	0.6	5.9	1.6	2.1	-
12. Cardiac angiography	Angiocardiography Coronary angiography Cardiac catheter	3.5	0.7	22.0	5.8	6.3	+
All angiography	*Cerebral. Cardiac. pulmonary. Abdominal. Aortography. peripheral*	*6.6*	*1.4*	*40.4*	*10.6*	*6.1*	
CT							
13. CT head	Head. brain. Facial bones	14.6	3.0	28.7	7.5	2.0	+
14. CT neck	Neck. cervical spine	0.6	0.1	1.4	0.4	2.4	+
15. CT chest	Chest/thorax	4.6	1.0	35.8	9.4	7.8	+
16. CT spine	Spine	1.4	0.3	5.9	1.5	4.2	+
17. CT abdomen	Abdominal organs	7	1.4	68.9	18.1	9.8	+
18. CT pelvis	Pelvic bone &/or organs	3.3	0.7	32.4	8.5	9.8	+
19. CT trunk	Trunk	0.4	0.1	4.2	1.1	10.4	+
All CT	*CT total*	*32.7*	*6.8*	*177.5*	*46.7*	*5.4*	
Interventional							
20. PTCA	PTCA	0.6	0.1	8.7	2.3	14.6	+
All interventional		*6.5*	*1.3*	*32.0*	*8.4*	*4.9*	
TOTAL 1-20 (excl. *'All' groups)*		**305.2**	**63.1**	**312.8**	**82.3**		
TOTAL 1-20 (inclu. *'All' groups)*		***315***	***65.2***	***354.9***	***93.4***		

0. All calculations are done without dental and nuclear medicine.
1. Based on the total exams frequency per 1000 population.
2. S = Collective effective dose.
3. Based on the total S per 1000 population.
4. Mean E = (S/y/1000 pop) / (no. exams/y/1000 pop).
5. + = increasing. - = decreasing. 0 = static.

Table A3.2: Top 20 Exams[0]

GERMANY	2000

Exam 'type'	Specific exams included in 'Exam type'	No. exams /y/1000 pop	% of total freq [1]	S /y/ 1000 pop [mSv] [2]	% of total S [3]	Mean E per exam [4] (mSv)	Trend in freq [5]
Radiography (plain film)							
1. Chest/thorax (lungs)	Lungs & ribs (chest/ribs) Thoracic inlet Bronchography	273	23.0	86	5.2	0.3	-
2. Cervical spine	Cervical spine	64	5.4	21	1.3	0.3	*all spine:* -
3. Thoracic spine	Thoracic spine	29	2.5	16	0.9	0.5	
4. Lumbar spine (inc. LSJ)	Lumbar spine Lumbo-sacral joint (LSJ) Sacro-iliac joints Sacrum & coccyx	56	4.8	94	5.7	1.7	
5. Mammography	Symptomatic & screening	41	3.5	25	1.5	0.6	0
6. Abdomen	Abdomen (plain film)	38	3.2	49	2.9	1.3	-
7. Pelvis & hip	Pelvis / Hip Orthopaedic pinning (incl hip)	92	7.7	67	4.0	0.7	0
Radiog/Fluoro							
8. Ba meal	Ba meal/stomach & duodenum	3.7	0.3	44	2.6	11.6	-
9. Ba enema	Ba enema/colon	2.5	0.2	39	2.4	15.9	-
10. Ba follow	Small intestine – Ba follow Small bowel enema	1.2	0.1	19	1.1	15.5	-
11. IVU	IVU	15	1.3	45	2.7	3.0	-
12. Cardiac angiography	Angiocardiography Coronary angiography Cardiac catheter	16	1.3	164	9.9	10.4	0
All angiography	*Cerebral. Cardiac. pulmonary. Abdominal. Aortography. peripheral*	*29*	*2.4*	*268*	*16.2*	*9.2*	*0*
CT							
13. CT head	Head. brain. Facial bones, face & neck	32	2.7	83	5.0	2.6	n/a
14. CT neck	Cervical spine	5	0.5	14	0.8	2.5	n/a
15. CT chest	Chest/thorax	15	1.2	112	6.7	7.6	n/a
16. CT spine	Lumbar spine	10	0.9	30	1.8	2.9	n/a
17. CT abdomen	Abdominal organs	22	1.9	417	25.2	18.6	n/a
18. CT pelvis	Pelvic bone &/or organs	4	0.3	39	2.4	10.6	n/a
19. CT trunk	Trunk	1	0.1	22	1.3	24.4	n/a
All CT	*CT total*	*89*	*7.5*	*716*	*43.2*	*8.1*	+
Interventional							
20. PTCA	PTCA	1.6	0.1	37	2.2	23.0	n/a
All interventional		*2.8*	*0.2*	*58*	*3.5*	*21.1*	*n/a*
TOTAL 1-20 (excl. *'All' groups*)		**723**	**61.0**	**1421**	**85.8**	2.0	-
TOTAL 1-20 (incl. *'All' groups*)		***737***	***62.1***	***1546***	***93.3***	***2.1***	-

0. All calculation are done without dental and nuclear medicine.
1. Based on the total exams frequency per 1000 population.
2. S = Collective effective dose.
3. Based on the total S per 1000 population.
4. Mean E = (S/y/1000 pop) / (no. exams/y/1000 pop).
5. + = increasing. - = decreasing. 0 = static.

Table A3.3: Top 20 Exames[0]

SWITZERLAND	1998

Exam 'type'	Specific exams included in 'Exam type'	No. exams /y/1000 pop	% of total freq [1]	S/y/ 1000 pop [mSv] [2]	% of total S [3]	Mean E per exam [4] (mSv)	Trend in freq [5]
Radiography (plain film)							
1. Chest/thorax (lungs)	Lungs & ribs (chest/ribs) Thoracic inlet Bronchography	213	27.9	26	2.59	0.12	0
2. Cervical spine	Cervical spine	22	2.9	23	2.31	1.05	+
3. Thoracic spine	Thoracic spine	11	1.38	37	3.71	3.54	+
4. Lumbar spine (inc. LSJ)	Lumbar spine Lumbo-sacral joint (LSJ) Sacro-iliac joints Sacrum & coccyx	40	5.22	163	16.2	4.09	0
5. Mammography	Symptomatic & screening	31	4.12	6	0.61	0.19	?
6. Abdomen	Abdomen (plain film)	20	2.67	47	4.71	2.32	0
7. Pelvis & hip	Pelvis / Hip Orthopaedic pinning (incl hip)	48	6.34	95	9.44	1.96	-
Radiog/Fluoro							
8. Ba meal	Ba meal/stomach & duodenum	3	0.42	59	5.92	18.5	0
9. Ba enema	Ba enema/colon	1	0.13	9	0.89	8.76	-
10. Ba follow	Small intestine – Ba follow Small bowel enema	0.37	0.05	16	1.58	42.3	?
11. IVU	IVU	4.59	0.6	18	1.84	4.02	-
12. Cardiac angiography	Angiocardiography Coronary angiography Cardiac catheter	3.63	0.48	40	4.04	11.1	-
All angiography	*Cerebral. Cardiac. pulmonary. Abdominal. Aortography. peripheral*	*9.87*	*1.3*	*78*	*7.75*	*7.86*	-
CT							
13. CT head	Head. brain. Facial bones	14	1.83	30	3.04	2.18	+
14. CT neck	Neck. Cervical spine	3.1	0.41	10	0.95	3.08	+
15. CT chest	Chest/thorax	6.93	0.91	61	6.11	8.83	+
16. CT spine	Spine	5.83	0.76	53	5.27	9.06	+
17. CT abdomen	Abdominal organs	13.8	1.81	116	11.6	8.43	+
18. CT pelvis	Pelvic bone &/or organs	1.03	0.14	7	0.72	7.04	+
19. CT trunk *	Trunk	–	–	–	–	–	–
All CT	*CT total*	*46.3*	*6.08*	*279*	*27.8*	*6.03*	+
Interventional							
20. PTCA	PTCA	1.37	0.18	15	1.48	10.8	-
All interventional		*3.77*	*0.49*	*36*	*3.6*	*9.57*	-
TOTAL 1-20 (excl. *'All' groups*)		**444**	**58.2**	**831**	**84.0**	**1.87**	**+**
TOTAL 1-20 (inclu. *'All' groups*)		***454***	***59.6***	***892***	***90.1***	***1.96***	**+**

0. All calculation are done without dental and nuclear medicine.
1. Based on the total exams frequency per 1000 population.
2. S = Collective effective dose.
3. Based on the total S per 1000 population.
4. Mean E = (S/y/1000 pop) / (no. exams/y/1000 pop).
5. + = increasing. - = decreasing. 0 = static.

* "CT trunk" is counted in "CT Chest" and "CT Abdomen".

Table A3.4: Top 20 Exams[0]

NORWAY	2002

Exam 'type'	Specific exams included in 'Exam type'	No. exams /y/1000 pop	% of total freq[1]	S/y/ 1000 pop [mSv] [2]	% of total S [3]	Mean E per exam [4] (mSv)	Trend in freq [5]
Radiography (plain film)							
1. Chest/thorax (lungs)	Lungs & ribs (chest/ribs) Thoracic inlet Bronchography	160.7	21.7	22.4	2.1	0.1	-
2. Cervical spine	Cervical spine	20.3	2.7	3.6	0.3	0.2	0
3. Thoracic spine	Thoracic spine	8.8	1.2	6.3	0.6	0.7	-
4. Lumbar spine (inc. LSJ)	Lumbar spine Lumbo-sacral joint (LSJ) Sacro-iliac joints Sacrum & coccyx	35.3	4.8	49.5	4.5	1.4	0
5. Mammography	Symptomatic & screening	76.7	10.3	8.8	0.8	0.1	+
6. Abdomen	Abdomen (plain film)	10.1	1.4	36.4	3.3	3.6	+
7. Pelvis & hip	Pelvis / Hip Orthopaedic pinning (incl hip)	74.9	10.1	45.3	4.2	0.6	+
Radiog/Fluoro							
8. Ba meal	Ba meal/stomach & duodenum	2.4	0.3	12.2	1.1	5.1	-
9. Ba enema	Ba enema/colon	6.2	0.8	77.7	7.1	12.5	-
10. Ba follow	Small intestine – Ba follow Small bowel enema	1.8	0.2	4.0	0.4	2.2	0
11. IVU	IVU	5.4	0.7	20.6	1.9	3.8	-
12. Cardiac angiography	Angiocardiography Coronary angiography Cardiac catheter	3.9	0.5	36.6	3.4	9.4	NA
All angiography	*Cerebral. Cardiac. pulmonary. Abdominal. Aortography. peripheral*	*10.1*	1.4	69.4	6.4	*6.9*	*0*
CT							
13. CT head	Head. brain. Facial bones	40.4	5.4	74.1	6.8	1.8	+
14. CT neck	Neck. cervical spine	2.3	0.3	7.9	0.7	3.4	NA
15. CT chest	Chest/thorax	10.9	1.5	125.4	11.5	11.5	+
16. CT spine	Spine	16.9	2.3	73.0	6.7	4.3	+
17. CT abdomen	Abdominal organs	17.9	2.4	226.2	20.7	12.6	+
18. CT pelvis	Pelvic bone &/or organs	11.4	1.5	106.2	9.7	9.3	+
19. CT trunk	Trunk	0	0	0	0	0	NA
All CT	*CT total*	*104.5*	14.1	641.9	58.9	*6.1*	+
Interventional							
20. PTCA	PTCA	0.6	0.1	6.0	0.5	9.9	NA
All interventional		3	0.4	39.3	3.6	13.1	NA
TOTAL 1-20 (excl. *'All' groups)*		**506.9**	**68.3**	**942.2**	**86.4**	**1.9**	**+**
TOTAL 1-20 (inclu. *'All' groups)*		***520.2***	***70.1***	***1037.5***	***95.2***	***2.0***	**+**

0. All calculation are done without dental and nuclear medicine.
1. Based on the total exams frequency per 1000 population.
2. S = Collective effective dose.
3. Based on the total S per 1000 population.
4. Mean E = (S/y/1000 pop) / (no. exams/y/1000 pop).
5. + = increasing. - = decreasing. 0 = static.

Table A3.5: Top 20 Exams[0]

NETHERLANDS *	2002

Exam 'type'	Specific exams included in 'Exam type'	No. exams /y/1000 pop	% of total freq [1]	S/y/ 1000 pop [mSv] [2]	% of total S [3]	Mean E per exam [4] (mSv)	Trend in freq [5]
Radiography (plain film)							
1. Chest/thorax (lungs)	Lungs & ribs (chest/ribs) Thoracic inlet Bronchography	137.4	25.5	4.9	1.1	0.04	o
2. Cervical spine	Cervical spine	11.2	2.1	0.2	0.05	0.02	
3. Thoracic spine	Thoracic spine	7.8	1.4	2.3	0.5	0.3	
4. Lumbar spine (inc. LSJ)	Lumbar spine Lumbo-sacral joint (LSJ) Sacro-iliac joints Sacrum & coccyx	20.0	3.7	8.8	2.0	0.4	
5. Mammography	Symptomatic & screening	59.0	11.0	13.4	3.0	0.2	+
6. Abdomen	Abdomen (plain film)	17.0	3.1	7.4	1.7	0.4	
7. Pelvis & hip	Pelvis / Hip Orthopaedic pinning (incl hip)	34.3	6.4	12.6	2.8	0.4	
Radiog/Fluoro							
8. Ba meal	Ba meal/stomach & duodenum	3.5	0.7	10.5	2.3	3.0	
9. Ba enema	Ba enema/colon	3.0	0.6	19.0	4.2	6.3	
10. Ba follow	Small intestine – Ba follow Small bowel enema	0.7	0.1	4.1	0.9	5.5	
11. IVU	IVU	1.7	0.3	5.2	1.2	3.0	
12. Cardiac angiography	Angiocardiography Coronary angiography Cardiac catheter	2.9	0.5	12.7	2.9	4.3	+
All angiography	*Cerebral. Cardiac. pulmonary. Abdominal. Aortography. peripheral*	*6.6*	*1.2*	*57.2*	*12.8*	*8.6*	+
CT							
13. CT head	Head. brain. Facial bones	13.7	2.5	16.0	3.6	1.2	+
14. CT neck	Neck. Cervical spine						
15. CT chest	Chest/thorax	7.2	1.3	39.2	8.8	5.5	+
16. CT spine	Spine	2.6	0.5	8.0	1.8	3.1	o
17. CT abdomen	Abdominal organs	10.9	2.0	116.0	26.0	10.6	+
18. CT pelvis	Pelvic bone &/or organs	0.9	0.2	6.9	1.6	7.4	o
19. CT trunk	Trunk						
All CT	*CT total*	*36.6*	*6.8*	*193.8*	*43.4*	*5.3*	+
Interventional							
20. PTCA	PTCA	1.4	0.3	16.1	3.6	11.7	
All interventional		*6.1*	*1.1*	*61.8*	*13.8*	*10.1*	+
TOTAL 1-20 (excl. *'All' groups*)		**335.2**	**62.3**	**303.3**	**67.9**		
TOTAL 1-20 (inclu. *'All' groups*)		***345.0***	***64.1***	***401.1***	***89.8***		

0. All calculation are done without dental and nuclear medicine.
1. Based on the total exams frequency per 1000 population.
2. S = Collective effective dose.
3. Based on the total S per 1000 population.
4. Mean E = (S/y/1000 pop) / (no. exams/y/1000 pop).
5. + = increasing. - = decreasing. 0 = static.

* For specific examinations estimates are based on the distribution from a few hospitals. Usually the numbers are based on overall categories. The specific exams included in each 'exam type' are not always exactly as described in the Table.

Table A3.6: Top 20 Exams[0]

SWEDEN	1995

Exam 'type'	Specific exams included in 'Exam type'	No. exams /y/1000 pop	% of total freq[1]	S/y/ 1000 pop [mSv] [2]	% of total S [3]	Mean E per exam [4] (mSv)	Trend in freq [5]
Radiography (plain film)							
1. Chest/thorax (lungs)	Lungs & ribs (chest/ribs) Thoracic inlet Bronchography	135	24	20.5	3	0.15	-
2. Cervical spine	Cervical spine	?					
3. Thoracic spine	Thoracic spine	?					
4. Lumbar spine (inc. LSJ)	Lumbar spine Lumbo-sacral joint (LSJ) Sacro-iliac joints Sacrum & coccyx	16	2.8	50	7	3	-
5. Mammography	Symptomatic & screening	85	15	21.5	3.2	0.25	0
6. Abdomen	Abdomen (plain film)	8	1.4	20.5	3	2.5	
7. Pelvis & hip	Pelvis / Hip Orthopaedic pinning (incl hip)	40	7	60	9	1.5	
Radiog/Fluoro							
8. Ba meal	Ba meal/stomach & duodenum	5	0.9	16	2.3	3	-
9. Ba enema	Ba enema/colon	11.4	2	91	13.3	8	-
10. Ba follow	Small intestine – Ba follow Small bowel enema						
11. IVU	IVU	11.4	2	57	8.3	5	
12. Cardiac angiography	Angiocardiography Coronary angiography Cardiac catheter	4.2	0.7	51	7.5	12	+
All angiography	*Cerebral. Cardiac. pulmonary. Abdominal. Aortography. peripheral*						
CT							
13. CT head	Head. brain. Facial bones	20.5	3.6	41	6	2	0
14. CT neck	Neck. cervical spine						
15. CT chest	Chest/thorax						
16. CT spine	Spine						
17. CT abdomen	Abdominal organs						
18. CT pelvis	Pelvic bone &/or organs						
19. CT trunk	Trunk	18.2	3.2	182	26.7	10	+
All CT	*CT total*	*40.4*	7	230	33.7	*5.7*	
Interventional							
20. PTCA	PTCA	0.7	0.1	14.8	2.2	22	+
All interventional		*3*	*0.5*	*28.5*	*4.2*	*10*	+
TOTAL 1-20 (excl. *'All' groups*)		**355**	**72**	**550**	**91.3**	**1.6**	
TOTAL 1-20 (inclu. *'All' groups*)		***360***	***73***	***570***	***94.3***	***1.6***	

0. All calculation are done without dental and nuclear medicine.
1. Based on the total exams frequency per 1000 population.
2. S = Collective effective dose.
3. Based on the total S per 1000 population.
4. Mean E = (S/y/1000 pop) / (no. exams/y/1000 pop).
5. + = increasing. - = decreasing. 0 = static.

Table A3.7: Top 20 Exams[0]

LUXEMBOURG	2002

Exam 'type'	Specific exams included in 'Exam type'	No. exams /y/1000 pop	% of total freq [1]	S/y/ 1000 pop [mSv][2]	% of total S [3]	Mean E per exam [4] (mSv)	Trend in freq [5]
Radiography (plain film)							
1. Chest/thorax (lungs)	Lungs & ribs (chest/ribs) Thoracic inlet Bronchography	174.2	18.9	34.9	1.9	0.2	0
2. Cervical spine	Cervical spine	29.8	3.2	6.0	0.3	0.2	-
3. Thoracic spine	Thoracic spine	18.4	2.0	12.8	0.7	0.7	-
4. Lumbar spine (inc. LSJ)	Lumbar spine Lumbo-sacral joint (LSJ) Sacro-iliac joints Sacrum & coccyx	58.5	6.4	110.3	6.1	1.9	-
5. Mammography	Symptomatic & screening	54.9	6.0	26.8	1.5	0.5	0
6. Abdomen	Abdomen (plain film)	20.7	2.2	20.7	1.1	1	0
7. Pelvis & hip	Pelvis / Hip Orthopaedic pinning (incl hip)	68.9	7.5	55.4	3.0	0.8	0
Radiog/Fluoro							
8. Ba meal	Ba meal/stomach & duodenum	5.6	0.6	50.3	2.8	9	-
9. Ba enema	Ba enema/colon	2.1	0.2	18.6	1.0	8.9	0
10. Ba follow	Small intestine – Ba follow Small bowel enema	0.5	0.1	4.4	0.2	8.8	0
11. IVU	IVU	6.7	0.7	23.5	1.3	3.5	0
12. Cardiac angiography	Angiocardiography Coronary angiography Cardiac catheter	8.3	0.9	82.6	4.5	10.0	0
All angiography	*Cerebral. Cardiac. pulmonary. Abdominal. Aortography. peripheral*	*15.6*	*1.7*	*209.4*	*11.5*	*13.4*	-
CT							
13. CT head	Head. brain. Facial bones	46.1	5.0	119.8	6.6	2.6	+
14. CT neck	Neck. cervical spine	8.0	0.9	20	1.1	2.5	+
15. CT chest	Chest/thorax	14.0	1.5	140.5	7.7	10	+
16. CT spine	Spine	23.0	2.5	207.3	11.4	9	+
17. CT abdomen	Abdominal organs	27.6	3.0	414.6	22.8	15	+
18. CT pelvis	Pelvic bone &/or organs	Are included in CT Abdomen					
19. CT trunk	Trunk	3	0.3	23.7	1.3	7.9	+
All CT	*CT total*	*134.8*	*14.6*	*993.2*	*54.5*	*7.4*	+
Interventional							
20. PTCA	PTCA	1.6	0.2	16.3	0.9	10.2	+
All interventional		*9.1*	*1.0*	*99.1*	*5.4*	*10.9*	+
TOTAL 1-20 (excl. *'All' groups*)		**571.9**	**61.9**	**1388.5**	**76.2**	**2.4**	**+**
TOTAL 1-20 (inclu. *'All' groups*)		***599.8***	***64.9***	***1665.4***	***91.4***	***2.8***	**+**

0. All calculation are done without dental and nuclear medicine.
1. Based on the total exams frequency per 1000 population.
2. S = Collective effective dose.
3. Based on the total S per 1000 population.
4. Mean E = (S/y/1000 pop) / (no. exams/y/1000 pop).
5. + = increasing. - = decreasing. 0 = static.

Table A3.8: Top 20 Exams[0]

DENMARK	1995

Exam 'type'	Specific exams included in 'Exam type'	No. exams /y/1000 pop	% of total freq [1]	S/y/ 1000 pop [mSv] [2]	% of total S [3]	Mean E per exam [4] (mSv)	Trend in freq [5]
Radiography (plain film)							
1. Chest/thorax (lungs)	Lungs & ribs (chest/ribs) Thoracic inlet Bronchography	129	24	14	2,9	0.11	0
2. Cervical spine	Cervical spine	11	2,0	2.3	0.5	0.21	0
3. Thoracic spine	Thoracic spine	12	2.2	6.7	1.5	0.56	0
4. Lumbar spine (inc. LSJ)	Lumbar spine Lumbo-sacral joint (LSJ) Sacro-iliac joints Sacrum & coccyx	24	4.5	21	4.4	0.88	0
5. Mammography	Symptomatic & screening	17	0.31	7.7	1.7	0.45	+
6. Abdomen	Abdomen (plain film)	5.7	1.1	12	2.6	2.1	0
7. Pelvis & hip	Pelvis / Hip Orthopaedic pinning (incl hip)	41	7.6	41	8.9	1.0	0
Radiog/Fluoro							
8. Ba meal	Ba meal/stomach & duodenum	1,5	0.28	27	5.8	18	-
9. Ba enema	Ba enema/colon	7.9	1,7	43	9.3	5.4	-
10. Ba follow	Small intestine – Ba follow Small bowel enema	1.6	0.29	5.9	1.3	3.7	-
11. IVU	IVU	7.2	1.3	40	8.7	5.5	-
12. Cardiac angiography	Angiocardiography Coronary angiography Cardiac catheter	-	-	-	-	-	-
All angiography	*Cerebral. Cardiac. Pulmonary. Abdominal. Aortography. Peripheral*	-	-	-	-	-	-
CT							
13. CT head	Head. brain. Facial bones	9.8	1.8	19	4.2	1.9	+
14. CT neck	Neck. Cervical spine	0.31	0,058	0.4	0.1	1.3	+
15. CT chest	Chest/thorax	2.7	0.49	28.5	6.1	11	+
16. CT spine	Spine	2.0	0.36	11.3	2.5	5.7	+
17. CT abdomen	Abdominal organs	0.62	0.012	8.8	1.9	14	+
18. CT pelvis	Pelvic bone &/or organs	0,17	0.033	1.4	0.3	8.3	+
19. CT trunk	Trunk	4,7	0.87	71	15	15	+
All CT	*CT total*	*24*	*4.5*	*141*	*30*	*5.9*	+
Interventional							
20. PTCA	PTCA	0.31	0,059	4.4	1,0	14	+
All interventional		*2.1*	*0.40*	*17*	*3.6*	*8.1*	+
TOTAL 1-20 (excl. *'All' groups*)		**279**	**49**	**351**	**79**	**1.3**	**+**
TOTAL 1-20 *(inclu. 'All' groups)*		**-**	**-**	**-**	**-**	**-**	**-**

0. All calculation are done without dental and nuclear medicine.
1. Based on the total exams frequency per 1000 population.
2. S = Collective effective dose.
3. Based on the total S per 1000 population.
4. Mean E = (S/y/1000 pop) / (no. exams/y/1000 pop).
5. + = increasing. - = decreasing. 0 = static.

Table A3.9: Top 20 Exams[0]

FRANCE	2002

Exam 'type'	Specific exams included in 'Exam type'	No. exams /y/1000 pop	% of total freq [1]	S/y/ 1000 pop [mSv][2]	% of total S [3]	Mean E per exam [4] (mSv)	Trend in freq [5]
Radiography (plain film)							
1. Chest/thorax (lungs)	Lungs & ribs (chest/ribs) Thoracic inlet Bronchography	91	11.5	5	0.7	0.05	-
2. Cervical spine	Cervical spine	29	3.7	2	0.3	0.07	+
3. Thoracic spine	Thoracic spine	24	3.1	19	2.8	0.80	
4. Lumbar spine (inc. LSJ)	Lumbar spine Lumbo-sacral joint (LSJ) Sacro-iliac joints Sacrum & coccyx	75	9.6	113	16.5	1.50	
5. Mammography	Symptomatic & screening	91	11.6	32	4.7	0.36	+
6. Abdomen	Abdomen (plain film)	25	3.2	15	2.1	0.58	-
7. Pelvis & hip	Pelvis / Hip Orthopaedic pinning (incl hip)	75	8.9	42	6.9	0.63	-
Radiog/Fluoro							
8. Ba meal	Ba meal/stomach & duodenum	2	0.3	5	0.8	3.00	-
9. Ba enema	Ba enema/colon	1	0.1	4	0.5	7.20	-
10. Ba follow	Small intestine – Ba follow Small bowel enema	1	0.1	2	0.3	3.00	-
11. IVU	IVU	6	0.8	16	2.3	2.50	-
12. Cardiac angiography	Angiocardiography Coronary angiography Cardiac catheter	4	0.5	36	5.3	9.00	?
All angiography	*Cerebral. Cardiac. pulmonary. Abdominal. Aortography. peripheral*	*9*	*1.1*	*80*	*11.7*	*9.00*	*?*
CT							
13. CT head	Head. brain. Facial bones	30	3.8	54	7.9	1.80	+
14. CT neck	Neck. cervical spine	1	0.1	2	0.2	2.50	?
15. CT chest	Chest/thorax	10	1.3	56	8.1	5.50	+
16. CT spine	Spine	22	2.8	87	12.7	4.00	+
17. CT abdomen	Abdominal organs	15	1.9	87	12.7	5.76	+
18. CT pelvis	Pelvic bone &/or organs						
19. CT trunk	Trunk	-	-	-	-	-	
All CT	*CT total*	*83*	*10.6*	*285*	*42.1*	*3.46*	+
Interventional							
20. PTCA	PTCA	2	0.3	16	2.3	9.00	?
All interventional		*6*	*0.8*	*46*	*6.8*	*8.25*	*?*
TOTAL 1-20 (excl. *'All' groups*)		**503**	**64.2**	**597**	**87.2**	**1.19**	
TOTAL 1-20 *(inclu. 'All' groups)*		***518***	***66.0***	***674***	***98.5***	***1.30***	

0. All calculation are done without dental and nuclear medicine.
1. Based on the total exams frequency per 1000 population.
2. S = Collective effective dose.
3. Based on the total S per 1000 population.
4. Mean E = (S/y/1000 pop) / (no. exams/y/1000 pop).
5. + = increasing. - = decreasing. 0 = static.

Table A3.10: Top 20 Exams[0]

BELGIUM	1996–2002 (Mean pro year)

Exam 'type'	Specific exams included in 'Exam type'	No. exams /y/1000 pop	% of total freq [1]	S/y/ 1000 pop [mSv] [2]	% of total S [3]	Mean E per exam [4] (mSv)	Trend in freq [5]
Radiography (plain film)							
1. Chest/thorax (lungs)	Lungs & ribs (chest/ribs) Thoracic inlet Bronchography	313[6]	27	29.4	1.7	0.09	-
2. Cervical spine	Cervical spine	34	2.9	9.2	0.5	0.27	-
3. Thoracic spine	Thoracic spine	19	1.6	26.6	1.5	1.4	-
4. Lumbar spine (inc. LSJ)	Lumbar spine Lumbo-sacral joint (LSJ) Sacro-iliac joints Sacrum & coccyx	38	3.3	116	6.5	3.1	-
* Full Spine		16	1.4	55.5	3.1	3.5	-
5. Mammography	Symptomatic & screening	99	8.5	19.8	1.1	0.20	0
6. Abdomen	Abdomen (plain film)	48	4.1	44.2	2.5	0.92	-
7. Pelvis & hip	Pelvis/Hip Orthopaedic pinning (incl hip)	88	7.6	73	4.1	0.83	-
Radiog/Fluoro							
8. Ba meal	Ba meal/stomach & duodenum	7.1	0.6	25.6	1.4	3.6	-
9. Ba enema	Ba enema/colon	6.1	0.5	39	2.2	6.4	-
10. Ba follow	Small intestine – Ba follow Small bowel enema	1.8	0.2	18	1.0	10	-
11. IVU	IVU	9.5	0.8	75	4.2	7.9	-
12. Cardiac angiography	Angiocardiography Coronary angiography Cardiac catheter	1.9	0.2	18.2	1.0	9.6	+
All angiography	*Cerebral. cardiac. Pulmonary. Abdominal. aortography. peripheral*	*14.9*	*1.3*	*185*	*10.4*	*12.4*	-
CT							
13. CT head	Head. brain. facial bones	42	3.6	96.6	5.5	2.3	0
14. CT neck	Neck. cervical spine						
15. CT chest	Chest/thorax	(in 19)				4.1	0
16. CT spine	Spine						
17. CT abdomen	Abdominal organs	(in 19)				11.3	
18. CT pelvis	Pelvic bone &/or organs	(in 19)					
19. CT trunk	Trunk (all chest, abdomen & pelvis exams)	65	5.6	448	25.3	6.9	
All CT[7]	*CT total*	*116*	*10*	*890*	*50.3*	*7.7*	+
Interventional							
20. PTCA	PTCA	1.6	0.1	24.5	1.4	15.3	+
All interventional		*3.6*	*0.3*				+
TOTAL 1-20 (excl. *'All' groups*)		**790**	**68.0**				
TOTAL 1-20 (incl. *'All' groups*)		***814***	***70.1***		**~92**		

0. All calculation are done without dental and nuclear medicine.
1. Based on the total exams frequency per 1000 population.
2. S = Collective effective dose.
3. Based on the total S per 1000 population.
4. Mean E = (S/y/1000 pop) / (no. exams/y/1000 pop).
5. + = increasing. - = decreasing. 0 = static.
6. Inclusive of Shoulder/Clavicle.
7. For *'All CT'* only 7 exam categories are taken into account: 1. CT of the skull and/or the facial bones (about 36% (CT Head) of all CT exams), 2. CT of the temporal bones and/or the sella tursica, 3. CT of the neck, chest (thorax) or abdomen (about 56% of all CT exams), 4. Vertebral CT on one level, 5. Vertebral CT on two or more levels, 6. CT of one or more limbs, 7. CT of a joint (of one or more limbs).