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

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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

Foreword

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The aim of this document is to provide practical guidance to Member States on the implementation of Council Directive97/43/EURATOM, Article 12, which 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.

The Commission was concerned about the lack of internationally accepted protocols for evaluating patient exposures from medical x-ray imaging procedures and with the existence of wide variations in the reported estimates of population doses between European countries. This guidance document provides the necessary basis for the development of a harmonised system for assessing patient doses in Member States, in order to improve the comparability of national population dose estimates in the future.

This document was developed under a multinational project called DOSE DATAMED involving partners and institutes from ten European countries with long experience of conducting national surveys of population exposure from medical radiology. The recommendations in the document are based on a comparative study on the methods and results of the most recent population dose surveys in each country. The results of this study are presented in two companion documents:

- DD Report 1, dealing with medical x-rays procedure, and
- DD Report 1(a), providing a brief review on nuclear medicine examinations.

Whereas the guidance is based on the situation in countries with relatively abundant resources for this type of study, the recommendations also allow for countries with less resources. Such countries will benefit from the recommendations made on minimum arrangements for making reliable population dose estimates and on approaches to avoid major sources of uncertainty. Additional help to countries with less resources is provided by the inclusion of average European data that can be used if specific national data are not available.

I am confident that the results of the DOSE DATAMED study and the recommendations provided in this guidance document will be of benefit to the professionals in the Member states responsible for estimating the dose distributions from medical exposure and will facilitate further harmonisation in this area among the Member States.

Augustin Janssens

Head of Radiation Protection Unit

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1 INTRODUCTION

The European Commission (EC), 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 the implementation of Article 12 of the Medical Exposure Directive of 1997 and to develop appropriate guidance [EC, 1997]. 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 healthcare. 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 studied and compared the methods and results of the most recent population dose surveys in each country and evaluated the uncertainties. **DD Report 1** presents the results and conclusions from this review of recent national surveys of population exposure from medical x-rays in Europe. A supplementary report - **DD Report 1(a)** - provides a brief review of the methods and results of recent national surveys of population exposure from diagnostic nuclear medicine procedures in eight of the DOSE DATAMED countries.

This report – **DD Report 2** – provides 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 improve the comparability of national population dose estimates in the future. In view of the relatively low contribution of nuclear medicine to population exposure compared to medical x-rays (4-14% in the various DOSE DATAMED countries), and the more straightforward and well-established methods for assessing patient doses for nuclear medicine examinations (see DD Report 1(a)), this guidance concentrates on population dose assessments for the x-ray imaging procedures used in diagnostic and interventional radiology. Nonetheless, much of the guidance given on the assessment of the frequency of x-ray procedures can be equally applied to nuclear medicine examinations.

Whereas the participants in this project generally represent those countries with relatively high levels of resources for this type of study, the following recommendations also cater for countries with fewer resources by identifying the minimum requirements for making reliable population dose estimates, by giving advice on how to avoid the major sources of uncertainty and by providing some average European data that can be used if specific national data are not available.

The report starts with a discussion of the purposes for making population dose assessments and describes the dose concepts and quantities used and their limitations when the particular age and sex distribution of patients undergoing medical exposures is taken into account. An indication is provided of the level of resources required for carrying out national population dose surveys of this complexity. Guidance is then provided on a common methodology for assessing the population dose. Methods for estimating the frequency of diagnostic and interventional procedures involving x-ray imaging, for estimating the typical patient doses involved with each procedure and for assessing the age/sex distributions of patients undergoing these procedures are described. A harmonised way of combining this information and presenting the results of population dose estimates is proposed. Finally, the potential in future surveys for using the information that is increasingly being stored electronically by modern medical imaging equipment and radiology information systems is discussed. A summary of the main recommendations is included at the end of the report.

2 PURPOSES FOR MAKING POPULATION DOSE ESTIMATES FOR MEDICAL X-RAYS, THE DOSE QUANTITIES USED AND THE RESOURCES REQUIRED

2.1 Purposes

Medical x-ray exposures have been the largest man-made source of population exposure to ionising radiation in developed countries for many years. Recent developments in medical imaging, particularly with respect to computed tomography (CT), have led to rapid increases in the number of relatively high-dose x-ray examinations performed, with significant consequences for individual patient doses and for the collective dose to the population as a whole. It is therefore important for the radiation protection and healthcare authorities in each country to make regular assessments of the magnitude and distribution of this large and increasing source of population exposure. The predominant objectives of these population dose assessments in recent years have been:

1. To observe trends in the annual collective dose and the annual average per caput dose from medical x-rays in a country with time (per caput dose = collective dose averaged over the entire population).
2. To determine the contributions of different imaging modalities and types of examination to the total collective dose from all medical x-rays.
3. To determine the relationship between the frequencies of different types of x-ray examination, the typical radiation doses given to patients and their contribution to the total collective dose.
4. To determine whether there are any regional variations within a country in the frequency and per caput dose from particular types of x-ray examination.
5. To compare the frequencies and the annual per caput doses from medical x-rays between countries.
6. To compare the contribution from medical x-rays with those from other natural and man-made sources of population exposure in a country.

These objectives provide information to national radiation protection and healthcare authorities that will enable them to prioritise and focus resources on the protection of those groups of patients in the population that are most highly exposed and consequently at highest risk. The comparisons with other countries afforded by objective 5 provide a valuable insight into the impact of the different healthcare systems and radiation protection practices in each country on the extent of the population exposure from medical x-rays. However, a vital feature of medical exposures is the direct benefit they provide to the healthcare of the exposed individual and so large per caput doses from medical x-rays should not necessarily be regarded as a bad thing. Medical exposures should be justified on an individual basis by offsetting the very small radiation risks for patients with the usually very substantial benefits from improved diagnosis leading to more effective treatment of their medical problem. A large per caput dose will be justified if all the individual medical exposures are justified and optimised.

DD Report 1 provides a review of recent national surveys of population exposure from medical x-rays in ten European countries that were undertaken primarily to meet the above objectives. However, an important characteristic of medical exposures is that they are far from being evenly distributed throughout the population. Even in developed countries only a small fraction of the population receives a medical x-ray exposure in any year. For example, Table 1 shows that 82% of the Danish population did not have any medical x-ray examinations in 2004 but nearly 10% had more than one, 1.6% had more than five and 0.4% of the population had more than 10 examinations in the year. Similar percentages have been found in other countries but these Danish data are the most recently available.

Table 1: Percentage of Danish population having medical x-ray exams in 2004 (x-ray examinations performed in dental practices are not included)

No. of exams per year	% of population
0	82
1	8.6
2	4.3
3	1.9
4	1.1
5	0.7
>5	1.6
>10	0.4

Moreover, the age distribution of patients undergoing x-ray examinations is heavily skewed towards the elderly and, taking all types of x-ray examination together, females tend to have more examinations than males. For example, Figure 1 shows that the number of patients undergoing one or more x-ray examinations in Denmark in 2004 peaks between the ages of 55-59 for both sexes, but that after 35 years of age females always outweigh males.

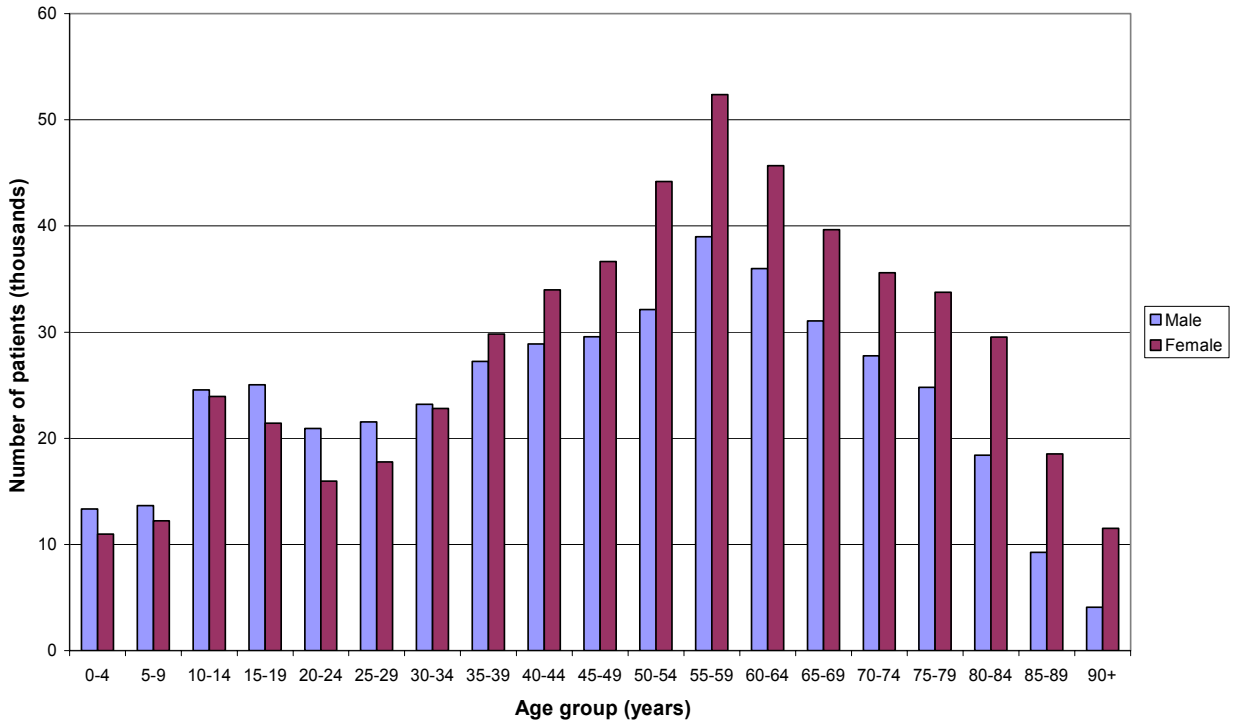

Figure 1: Numbers of patients in the Danish population having one or more x-ray examinations in 2004 as function of age and sex

The heavy bias towards elderly patients is shown more dramatically in Figure 2 where the percentage of Danish people in each age and sex band having one or more x-ray examinations in 2004 is shown. Only about 10% of children and young adults up to the age of 40 years had any x-ray examinations in 2004, whereas it had risen to 30% by the age of 70 and to over 40% by the age of 85 for both sexes.

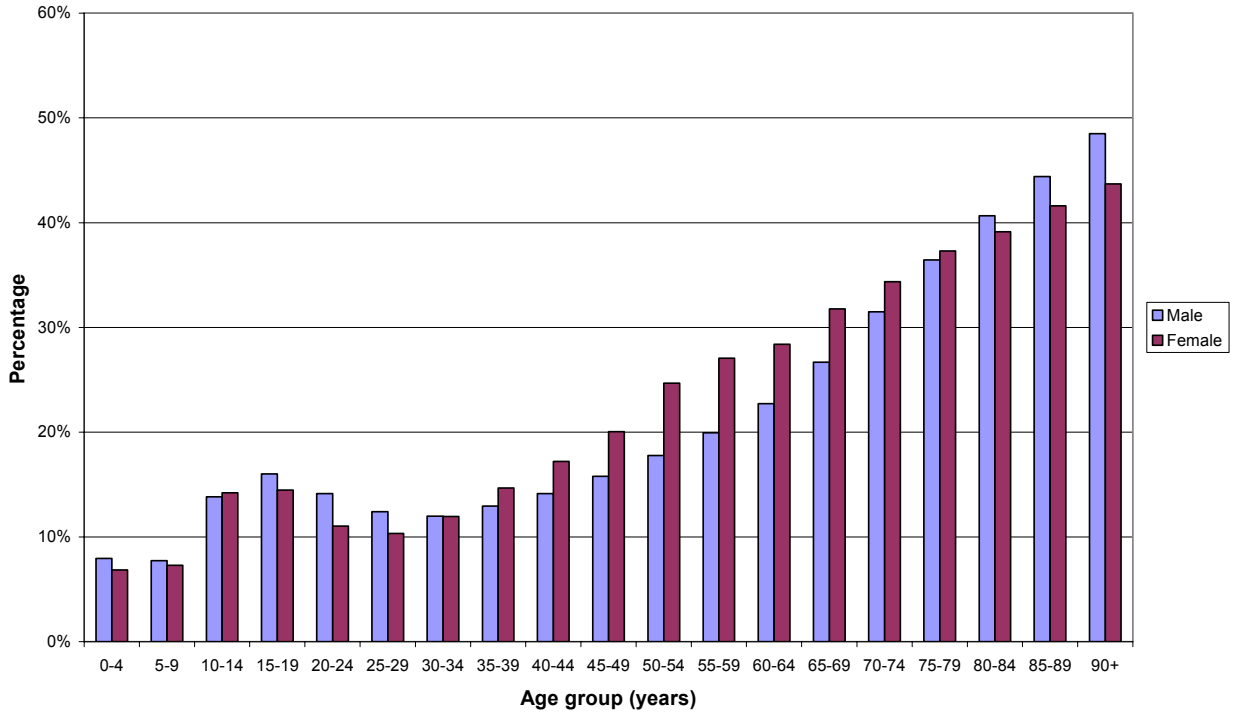

Figure 2: Percentage of people in each age/sex band having one or more x-ray examinations in Denmark in 2004

Population dose assessments based purely on collective dose or average per caput dose, provide no information on these very large non-uniformities in the way that the doses are distributed around the population.

Denmark is one of the few countries with an accessible national healthcare database that contains information on the identity of individual patients being examined, rather than on just the number of examinations being conducted. In most countries the statistics that are collected for population dose surveys do not record when different x-ray examinations are performed (or the same x-ray examination is repeated at another time) on the same patient. Consequently for most countries it is currently not possible to determine how x-ray examinations are distributed between individual members of the population in the manner shown in the above Table and Figures. However, information on the age and sex (but not the identity) of patients undergoing x-ray examinations is often available, so that the age and sex distributions for patients undergoing particular types of x-ray examination can be determined.

Article 12 of the EC Medical Exposure Directive (EC, 1997) requires Member States to determine the distribution of individual dose estimates from medical exposure for the population **and for relevant reference groups of the population**, as may be deemed necessary by the Member State. 'Reference groups' that have been most commonly studied for diagnostic medical exposures relate to groups of patients suffering from a particular medical condition and thus undergoing particular types of x-ray examination, or groups of the population that are asymptomatic but are invited to participate in screening programmes for specific diseases that involve a particular type of x-ray examination (e.g. mammography for breast cancer screening). In both cases information on the age and sex distributions for the groups of patients undergoing particular types of x-ray examination can be combined with

suitable patient dose estimates to provide more detailed information on how medical x-ray doses are distributed around the population.

The predominant effect of radiation exposures at the levels encountered in diagnostic radiology is an increased probability of cancer over the remaining lifespan of the patients, which is critically dependent on the age and sex distribution of the exposed population. A thorough assessment of the population dose from medical x-rays should therefore include information on the age and sex distribution of the patients undergoing specific types of x-ray examination, particularly those making major contributions to the total collective dose.

2.2 Dose quantities used

The United Nations Scientific Committee on the Effects of Atomic Radiation (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. the 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 more 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 or the annual average per caput effective dose. It has also reported the age and sex distribution of patients undergoing some common types of x-ray examination in terms of three broad age bands (0-15 years, 16-40 years, >40 years) for both sexes combined, and the overall distribution between male and female patients for all ages [UNSCEAR, 1993 and 2000].

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 radiation-induced cancer risk as the non-uniform body exposure. 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. Since the collective population dose depends on the size of the population, it is often 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 collective effective dose and the average per caput effective dose are therefore related to 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.

The relationship between effective dose and the probability of delayed radiation effects is critically dependent on the age and sex distribution of the exposed population. As Figures 1 and 2 show, 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. The variation with age at exposure and sex of the lifetime probability of radiation-induced fatal cancer following uniform whole body exposure is shown in Figure 3. This Figure is based on radiation risk projection models developed by NRPB in 1993 from appropriate epidemiological studies that were combined with UK life tables and baseline cancer rates to estimate age- and gender-specific cancer-induction risk coefficients for the UK population [Wall, 2004]. Adding the risks for each type of cancer modelled gives the total fatal cancer risk coefficients shown in Figure 3. The risk coefficients for children below the age of 15 are seen to be about twice those for adults between 30 and 60 years old, with a steady fall in lifetime risk above the age of 60.

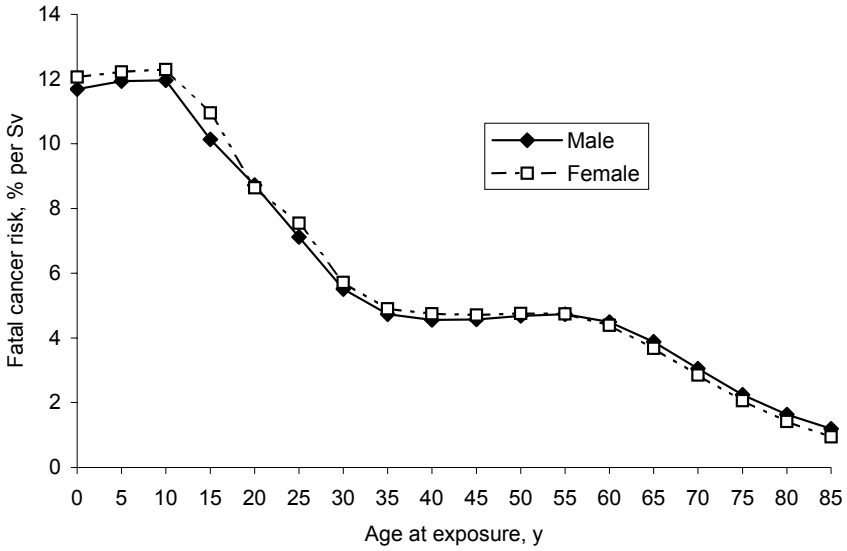

Figure 3: Total excess fatal cancer risk for uniform whole body exposure as a function of age at exposure and sex (Wall, 2004)

There is little difference in the total fatal cancer risks between the two sexes using these 1993 risk models, but more recent estimates of age/sex specific cancer risks by the BEIR Committee [BEIR, 2006] show risks to be slightly higher for females than males, particularly at young ages.

However, for real medical x-ray exposures the dose distribution is not uniform throughout the body. Since the radiation risks for different organs vary with age at exposure and sex in different ways, the total fatal cancer risk for a particular x-ray examination may not vary with age and sex in exactly the same way as shown in Figure 3 for uniform whole body exposure.

Because of these variations in risk with age and sex, collective effective dose estimates for medical exposures should not be used for assessing radiation risks 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 collective or per caput effective doses for all the objectives listed at the beginning of this section (except number 6) where

only relative comparisons of the exposures of populations with similar age and sex distributions are being made. ICRP, in its latest report on Radiation Protection in Medicine [ICRP, 2007b], confirms that effective dose can be of value for comparing doses from different diagnostic procedures and for comparing the use of similar imaging technologies and procedures in different hospitals and countries as well as the use of different technologies for the same type of medical examination, provided that the patient populations are similar with regard to age and sex.

In objective 6, the collective effective doses from different natural and man-made sources of ionising radiation are being compared, where the age/sex distributions of the populations exposed to each source could be markedly different. In this situation, a method should be developed for taking account of the differences between the age/sex distribution of patients and the age/sex distributions of those exposed to the other sources and the relationship between age at exposure, sex and radiation risks. This could take the form of a modifying factor to be applied to the collective effective dose from medical exposures that takes account of the reduced risks per unit dose for patients who tend to be more elderly than the general population. For example, generic modifying factors of 0.6 – 0.7 encompassing the age/sex distribution of patients undergoing all types of diagnostic x-ray examination have been published in studies from the UK, Germany and the Netherlands [Wall, 1991; Kaul et al, 1997; Beentjes, 1991].

In summary, for the estimation of population doses as required by Article 12 of the EC Medical Exposure Directive and to meet the objectives listed at the beginning of this section, the annual collective and per caput effective doses for the totality of all x-ray examinations conducted in a country and for those specific examinations making major contributions to the total, need to be calculated. In addition, information on the age and sex distribution of the patients undergoing the types of x-ray examination making major contributions to the total collective dose will be valuable for relating the collective doses to the collective detriment in any subsequent studies using age-, sex- and organ-specific radiation risk models.

2.3 Resources required

A nationwide survey on the exposure of the population from medical x-rays is a considerable endeavour that requires a heavy commitment of time and resources. Therefore, it is essential, when planning such a survey, to assess and ensure the availability of the necessary resources, both financial and human (with various types of expertise) for conducting it in the best way.

Conducting the survey goes through various stages: design, pilot study, dose measurement campaign, frequency data collection, data processing, data analysis, discussion of the results, drawing conclusions and recommendations, publication and diffusion of the final report to the concerned institutions, dissemination of the main results through scientific publications in peer-reviewed journals. The whole process may easily take three years.

It should be appreciated that when all the expenses are taken into account (salaries, equipment, postage, travel, meetings, overheads), a nationwide survey may cost (depending on the size of the country and hence the size of the sample) between €¼ M and €½ M.

At least two senior scientists, whose responsibility is to coordinate the whole project and to assure the scientific quality of the results, should be available to oversee the conduct of the survey. Moreover, the team conducting the survey must have expertise (internally or by external consultancy) in areas such as:

- Radiology: this expertise is necessary for a good definition of the types of examinations, for working-out typical values of the technical parameters to use in dose estimation, and for explaining the results.
- Dosimetry: this expertise is necessary for dose assessment for the various modalities and the different types of examinations, either by measurement, by calculation or by computation.
- Public health: this expertise is necessary for establishing a proper methodology of the survey and analysing the trends revealed by it.
- Statistics: this expertise is necessary for analysing the results, assessing uncertainties, and developing survey consolidation methods.
- Project management: this expertise is necessary for getting the survey to progress in an optimal way, by assuring the respect of the timing and the proper use of the resources.

It is essential to involve the national public health and the radiation protection authorities in the project. Their support is valuable in order to get a high rate of positive response. These authorities have the political and legal tools to influence the behaviour of the institutions chosen to be part of the survey sample. Often a mere letter of support from these national authorities will be sufficient.

It is also useful to collaborate with the professional bodies associated with medical radiology from the first stage of the survey. A support group composed of representatives from the professional societies of radiologists, radiographers, medical physicists and referring physicians might be helpful. The support group can provide valuable assistance throughout the study in establishing the methodology, in gathering the data from their affiliates (messages of encouragement to the participating practices and hospitals), in giving constructive criticisms of the results and the discussion, and in drawing the conclusions and disseminating the recommendations.

To calculate the collective effective dose, information is needed on the annual numbers of all important types of medical radiology procedure in each country and on representative effective doses for each procedure. Guidance on gathering this information is given in the next two sections of this report (3 and 4). Guidance on assessing the age and sex distributions of x-ray patients is given in section 5, and a harmonised methodology for processing these data and presenting population dose estimates is proposed in section 6.

3 GUIDANCE ON ASSESSING THE FREQUENCY OF X-RAY EXAMINATIONS

There are over 200 different types of x-ray examination or x-ray-guided interventional procedure conducted in European countries at the present time, of widely ranging complexity. An x-ray examination may consist of a single radiograph or several radiographs with or without the use of fluoroscopy, or one or a series of CT scans. Images may be taken with and/or without contrast media to enhance soft tissues. Several organs or body parts might be involved in one examination depending on the clinical indication for the examination. In order to compare x-ray examination frequency data between countries (and to assign typical effective dose values to examinations), it is crucial that an "x-ray examination" is defined and counted in a consistent way.

The recommended definition of an x-ray examination developed in the DOSE DATAMED project is:
'An x-ray examination or interventional procedure is defined as one or a series of x-ray exposures of one anatomical region/organ/organ system, using a single imaging modality (i.e. radiography/fluoroscopy or CT), needed to answer a specific diagnostic problem or clinical question, during one visit to the radiology department, hospital or clinic'.
For example, an examination of the GI tract with several radiographs combined with fluoroscopy performed during the same visit, is considered to be *one* examination, whereas an AP abdomen radiograph followed by an abdominal CT examination, even during one visit, counts as *two* examinations.

Information on the annual numbers of x-ray examinations conducted in a country can be obtained from the Radiology Information Systems (RIS) in a representative sample of hospitals and practices or from national health insurance databases. In most countries, predefined code systems are used in the RIS or the insurance database to describe the types of x-ray examination that take place. The code systems are mostly designed to meet national systems for reimbursement and are not always ideally suited for counting the number of x-ray examinations that take place as defined above. Consequently, the number of specific types of examination for which frequency data are available is likely to vary considerably between countries, depending on the degree of detail in their respective coding systems.

The first problem in assessing the frequency of x-ray examinations is to decide how much detail is required in the differentiation and categorisation of x-ray examinations to be able to make a reliable estimate of the total collective dose and the major contributors to it.

3.1 How to categorise x-ray examinations

To study this problem, an exhaustive list of all types of x-ray examination and interventional procedure known to be in current clinical practice in the ten DOSE DATAMED countries has been drawn up. The list of purely diagnostic x-ray examinations has been divided into three according to imaging modality, and interventional procedures involving x-ray guidance are listed separately. They are shown in the 2nd column of Tables 2-5:

Table 2: Plain film radiography (without contrast media)
Table 3: Radiography/fluoroscopy (mostly involving contrast)
Table 4: Computed tomography
Table 5: Interventional procedures

There are a total of about 225 specific types of examination or procedure listed in the four Tables and they have been arranged according to the region of the body or the organs/tissues being imaged.

The coding systems were sufficiently detailed to derive frequency data for all these examinations in only three of the DOSE DATAMED countries (Switzerland, Norway and Luxembourg). In most of the other countries it was only possible to derive more aggregated frequency data based on groups of examinations. The third column of Tables 2-5, headed 'DOSE DATAMED Exam Categories', shows how the specific examination types were most commonly grouped together in these other countries. There are a total of about 70 examination categories in the four Tables and information on how the annual numbers of examinations are distributed between these 70 categories will still provide a very good indication of radiology practice in a country for use in estimating the population exposure.

This level of differentiation and categorisation of x-ray examinations is more detailed than that used by UNSCEAR in its latest published assessment of medical radiation exposures worldwide [UNSCEAR, 2000], where frequency data is reported for about 30 categories of medical and dental x-ray examination and interventional procedure. The categories used in the Medical Radiation Exposure Annex to the UNSCEAR 2000 report are shown in the fourth column of Tables 2-5. Whereas only a few relatively infrequent or low-dose examinations are not covered by the UNSCEAR categories in Tables 2 and 3 (plain film radiography and radiography/fluoroscopy examinations), a number of increasingly frequent and high-dose CT examinations and interventional procedures are covered in insufficient detail by the very broad UNSCEAR 2000 categories in Tables 4 and 5. In the current UNSCEAR questionnaire (distributed in 2001) slightly more detailed information is requested for CT examinations and interventional procedures (these UNSCEAR 2001 categories are shown in the fifth column of Tables 4 and 5) but they still do not provide sufficiently detailed information on these increasingly important examinations and procedures.

Table 2: Plain film radiography

Region of body	Specific exam types	DOSE DATAMED exam categories	UNSCEAR 2000 categories
Head	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	Skull & facial bones	Head
	Dacryocystography (tear ducts) Sialography (salivary glands) Eyes/orbits	Head - soft tissue	
Neck	Cervical spine	Cervical spine	Cervical spine
	Larynx Pharynx Trachea	Neck – soft tissue	
Chest/Thorax	Thoracic spine	Thoracic spine	Thoracic spine
	Shoulder blades/ scapulae Collar bone(s) / clavicle(s) Acromio-clavicular joint Sterno-clavicular joint Manubrio-sternal joint Sternum	Shoulder girdle	
	Ribs	Ribs	Chest (radiography) Chest (photo-fluoro.) Chest (fluoroscopy)
	Lung Thoracic inlet Bronchography	Chest/thorax/lung	
Abdomen	Lumbar spine	Lumbar spine	Lumbar spine
	Lumbo-sacral joint	Lumbo-sacral joint only	
	Abdomen (plain film, patient supine or erect)	Abdomen	Abdomen
Pelvis	Pelvic bones - Ilium/ischium/pubis - Sacrum - Sacro-iliac joint - Coccyx	Pelvic bone	Pelvis & hips
	Pelvimetry (obstetric)		Pelvimetry
	1 or both hips	Hips	
	Pelvis (soft tissue)	Pelvis (soft tissue)	

Region of body	Specific exam types	DOSE DATAMED exam categories	UNSCEAR 2000 categories
Limbs	Upper arm (humerus)	Upper arm	Limbs & joints
	Elbow	Elbow	
	Forearm (radius & ulna) Wrist (scaphoid) Hand - Fingers & thumbs	Forearm, wrist & hand	
	Femur	Femur	
	Knee Knee cap (patella)	Knee	
	Lower leg (tibia & fibula) Ankle Foot Calcaneum (heel) Toes	Lower leg, ankle & foot	
	Whole leg	Leg length	
Trunk	Scoliosis	Whole spine	
Head & trunk	Whole skeleton	Skeletal survey	
Teeth & gums	1-2 periapical films 1-2 bitewing fims 1 occlusal film	Intra-oral <3 films	Dental (intraoral)
	>2 periapical films Periapical full mouth survey >2 bitewing films	Intra-oral >2 films	
	Panoramic full mouth scan	Panoramic	Dental (panoramic)
Breast	Symptomatic: - 1 or 2 views of 1 or both breasts Screening: - 1 or 2 views of both breasts	Mammography	Mammography (screening or clinical diagnosis)

Table 3: Radiography/fluoroscopy (excluding interventional procedures)

Region of body	Specific exam types	DOSE DATAMED exam categories	UNSCEAR 2000 categories
GI tract (Neck + chest + abdomen)	Oesophagus (Ba swallow) Stomach & duodenum (Ba meal) Small intestine (Ba follow) Enteroclysis (small intestine enema)	Oesoph. & stomach & small intestine	GI tract (upper)
	Colon (Ba enema)	Colon	GI tract (lower)
	Defecography	Defecography	
Biliary tract	Retrograde cholangiography Operative cholangiography Intravenous cholangiography T drain cholangiography Transhepatic cholangiography Endoscopic retrograde cholangio-pancreatography (ERCP) Retrograde pancreatography Cholecystography	Biliary tract	Cholecystography
Uro-genital tract	Intravenous urography (IVU)	IVU	Urography
	Retrograde pyelography Nephrostography	Kidneys & ureters	
	Retrograde cystography Micturitional cysto-urethrography (MCU) Urethrography	Bladder & urethra	
	Hysterosalpingography	Gynaecological	
Spinal cord	Cervical myelography Thoracic myelography Lumbar myelography Sacral myelography Whole spine myelography	Myelography	
Joints	Temporal-mandibular joint arthrography Shoulder arthrography Hip arthrography Elbow arthrography Wrist arthrography Knee arthrography Ankle arthrography	Arthrography	Included in Limbs & joints (Table 2)
Angiography	Cerebral angiography Petrous phlebography	Cerebral angiography	Cerebral angiography
	Coronary angiography (CA) - coronary arteries only - cor arts + L ventricle - cor arts + L ventricle + aorta Thoracic aortography	Cardiac angiography (angiocardiography)	Cardiac angiography
	Bronchial arteriography Pulmonary arteriography Upper venacavography	Thoracic angiography	All angiography (including cerebral & cardiac)
	Abdominal aortography Renal arteriography Mesenteric arteriography Lower venacavography Renal phlebography Suprarenal phlebography	Abdominal angiography	
	Pelvic arteriography Ovarian phlebography Spermatic phlebography	Pelvic angiography	
	Upper & lower limb arteriography Upper & lower limb phlebography	Peripheral angiography	

Region of body	Specific exam types	DOSE DATAMED exam categories	UNSCEAR 2000 categories
Lymphangiography	Thoracic lymphangiography Abdominal lymphangiography Pelvic lymphangiography Upper & lower limb lymphangiography	Lymphangiography	

Table 4: CT Examinations

Region of body	Specific exam types	DOSE DATAMED exam categories	UNSCEAR 2000 categories	UNSCEAR 2001 categories
Head	Skull - Orbits - Temporal bone - Petrous bone - Temporal-mandibular joint - Sella turcica Face Dental	Skull & facial bones	Head	Head
	Brain - Cerebrum - Posterior fossa - Brain vascular Pituitary gland	Brain		
	Sinuses Internal auditory meatus Nasal cavity Mouth	Head soft tissues		
Neck	Cervical spine	Cervical spine		
	Neck Larynx Pharynx Neck vascular	Neck		
Chest	Thoracic spine	Thoracic spine	Body	Thorax
	Mediastinum Lungs standard Lungs High Resolution Heart Thoracic aorta Lungs vascular	Chest/thorax		
Abdomen	Lumbar spine	Lumbar spine		Abdomen
	Full abdomen Upper abdomen	Abdomen		
	Liver / pancreas Kidneys / Supra-renal glands	Liver, pancreas & kidneys		
Pelvis	Hip / pelvic bone Sacrum/coccyx Sacro-iliac joint	Pelvic bones		
	Pelvimetry (obstetric)	Pelvimetry		
	Pelvis (soft tissues/vascular)	Pelvis		
Neck + chest + abdomen	Full spine	Full spine		
Chest + abdomen	Chest/abdomen	Chest & abdomen		
Abdomen + Pelvis	Abdomen/pelvis	Abdomen & pelvis		
Chest + abdomen + pelvis	Whole trunk	Chest, abdomen & pelvis		
Limbs	Shoulder Elbow Wrist Hand Leg Thigh Knee Calcaneum Ankle Foot	Limbs		

Table 5: Interventional Radiology

Region of the body	Specific procedure types	DOSE DATAMED procedure categories	UNSCEAR 2000 categories	UNSCEAR 2001 categories
Head & neck	Cerebral dilatation/stenting Cerebral embolisation (AVM, aneurysm, tumor) Cerebral thrombolysis Head & neck puncture	Cerebral interventions	All interventional	Cerebral
Chest	Coronary dilatation/stenting (PTCA)	PTCA	PTCA	Cardiac (PTCA)
	Cardiac pacemaker fitting (temporary or permanent)	Pacemaker	All interventional	Cardiac
	Central venous line fitting	Hickman line		Vascular (non-cardiac)
	Cardiac thermo-ablation Valvuloplasty IVC (caval) filter fitting Oesophagus dilatation/stenting Thoracic dilatation/stenting Thoracic embolisation Thoracic thrombolysis Thoracic region biopsy Electrophysiology	Other thoracic intervents.		Cardiac Other Vascular (non-cardiac) Other
Abdomen	Bile duct dilatation/stenting Bile duct drainage Bile duct stone extraction Renal artery dilatation/stenting Renal drainage Lithotripsy Nephrostomy	Biliary & urinary systems		
	TIPS (liver)	TIPS		
	Abdominal dilatation/stenting Abdominal embolisation Abdominal thrombolysis Abdominal region biopsy	Abdominal interventions		Vascular (non-cardiac)
Pelvis	Pelvic vessel dilatation Pelvic vessel embolisation Pelvic vessel thrombolysis	Pelvic interventions		
Limbs	Upper limb dilatation Upper limb embolisation Upper limb thrombolysis Popliteal dilatation (behind knee) Lower limb dilatation Lower limb embolisation Lower limb thrombolysis Limbs biopsy	Limb interventions		

However, many of the 70 examination categories in column 3 make only a minimal contribution to the collective population dose, so if this level of data collection is not possible it would be best to give priority to those examination types and categories that contribute most to the collective effective dose. The 20 types of examination or procedure that were consistently found to be amongst the highest contributors to the collective effective dose in all ten DOSE DATAMED countries are listed in Table 6. The range of the percentage contribution to the total frequency and to the total collective dose (S) from each examination over the ten countries is shown in the second and third columns of the Table. Together these 'Top 20 Exams' contributed between 50-70% to the total frequency and between 70-90% of the total collective effective dose from all medical x-ray procedures (excluding dental) in each country.

Table 6: Top 20 Exams

Exam type or category	% of total frequency*	% of total S*
Plain film radiography		
1. Chest/thorax	12 - 29	0.7 – 5.2
2. Cervical spine	2.0 – 5.4	0.05 – 2.3
3. Thoracic spine	1.0 – 3.1	0.5 – 3.7
4. Lumbar spine (inc. LSJ)	2.8 – 9.6	2.0 - 17
5. Mammography	0.3 – 15	0.6 – 4.7
6. Abdomen	1.1 – 4.3	1.1 – 4.7
7. Pelvis & hip	6.3 – 10	2.8 – 9.4
Radiography/Fluoroscopy		
8. Ba meal	0.3 – 0.9	0.8 – 5.9
9. Ba enema	0.1 – 2.0	0.5 - 13
10. Ba follow	0.05 – 0.3	0.2 – 1.6
11. IVU	0.3 – 2.0	1.2 – 8.7
12. Cardiac angiography	0.2 – 1.3	1.0 – 9.9
All angiography	*1.1 – 2.4*	*6.4 - 16*
CT		
13. CT head	1.8 – 5.4	3.0 – 7.9
14. CT neck	0.06 – 0.9	0.1 – 1.1
15. CT chest	0.5 – 1.5	6.1 - 12
16. CT spine	0.3 – 2.8	1.5 - 13
17. CT abdomen	0.01 – 3.0	1.9 - 26
18. CT pelvis	0.03 – 1.5	0.3 – 9.7
19. CT trunk	0.1 – 5.6	1.1 - 27
All CT	*4.5 – 15*	*28 - 59*
Interventional		
20. PTCA	0.1 – 0.3	0.5 – 3.6
All interventional	*0.2 – 1.3*	*3.5 - 14*
TOTAL 1-20	**50-70**	**70-90**

* Range over 10 DOSE DATAMED countries

Detailed descriptions of these 'Top 20 Exams', including some common clinical indications for the examinations and commonly used imaging techniques are given in Appendix 1.

In summary, the most reliable and accurate approach to estimating the collective dose from medical x-rays in a country will undoubtedly be to collect frequency data (and estimate typical effective doses) for all 225 specific types of examination listed in the second column in Tables 2-5. However, this will not be possible for many countries, in which case the second best approach will be to gather frequencies (and estimate doses) for the 70 categories of examinations listed in the third column in Tables 2-5. This amount of detail in the frequency of the different categories will still provide a very good indication of radiology practice in a country and, as long as a mean effective dose can be estimated for the specific x-ray examinations included in each category, a reasonably accurate assessment of the total collective dose to the population should be possible. If that is not possible either, it would be best to give priority to the twenty examination types and categories that contribute most to the collective effective dose, as listed in Table 6. These cover 70–90% of the total collective dose from all medical x-ray procedures in recent surveys in European countries and these percentages are likely to be even higher in the future. If the frequency and mean effective doses for these 20 examinations can be assessed, the resulting collective dose will provide as good a measure of population exposure as possible with the minimum of effort and allocated resources.

3.2 X-ray examination frequency survey methods

The methods used for assessing the annual frequency of x-ray examinations basically fall into 2 types:-

(a) Annual numbers of examinations 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 all (or at least a large proportion) of radiology practice in the country.

If frequency data are derived by method (a) from a relatively small sample of hospitals or practices, steps should be taken to ensure that the sample is as representative of national radiology practice as possible. All types of hospital and radiological practice should be included in the sample in similar proportions to those occurring nationally. A list of all the different types of hospital, clinic or institute that might be involved in providing medical radiology services in a country is shown in Table 7 (taken from Table 2 of DD Report 1). This list can be used to check that all important contributors to national radiology practice have been included in the sample.

It is important to make clear whether dental radiology conducted by dentists in ‘Dental Practices’ is included in the population dose assessments or not. 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. However, the inclusion of ‘School Dental Services’, ‘Health Checks at Borders’, ‘Prisons’, ‘TB Screening Units’ and ‘Armed Forces Hospitals/Units’ 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 is likely to be insignificant in most European countries.

Table 7: Healthcare providers involved with X-ray imaging

1	University Hospitals
2	Other State Hospitals
3	Private Hospitals
4	Private Radiology Institutes
5	General Practices
6	Specialist Practices (e.g. Cardiology, Gastroenterology, Orthopaedics, Pneumology, Urology, Vascular surgery)
7	Occupational Medicine
8	Chiropractic Clinics
9	Dental Practices
10	Dental Institutes
11	School Dental Services
12	Health checks at borders
13	Prisons
14	TB screening units
15	Breast cancer screening units
16	CT screening units
17	Armed forces hospitals/units

If method (a) is used, information on the annual numbers of x-ray examinations conducted in the hospitals, institutes and practices at the top of this list should be available from the computerised Radiology Information Systems (RIS) that are now widely in place in most hospitals throughout Europe. As discussed in the previous section, predefined code systems are used in most RIS's to describe the types of x-ray examination that take place, but there is currently no single harmonised code and many different coding systems may exist even in the same country. Thus the accuracy of the frequency data that can be derived from the RIS, depends on how reliably the coded information stored in the RIS (or held centrally in health insurance data bases, if method (b) is used) can be translated into actual numbers of examinations.

One has to be aware that code systems might vary with time. Several countries have experienced that almost every year there are minor changes in the coding system. Close cooperation between those responsible for assessing the population dose and the designers of examination code systems is necessary in order to obtain reliable frequency data. Radiological code systems will undoubtedly differ between European countries for a long time. This means that the number of specific examination types or groups of examinations for which frequency data are available will vary greatly from country to country. This problem and ways to overcome it have been discussed in section 3.1.

There are a number of ways of scaling up the annual numbers of each type of examination category observed in the sample survey to the whole country. They can be based on the relative numbers of radiology service providers, patients, or the total numbers of x-ray examinations, in the sample and the whole country, depending on what data are available. Whatever method is used, the assumption is invariably made that the pattern of

examinations seen in the sample is the same in the rest of the country. The reliability of the estimates of national frequencies therefore depends critically on how representative the sample survey is of radiology practice in the country as a whole.

3.3 Identifying uncertainties in frequency estimates

Depending on the method for deriving frequency data (method (a) - data from a sample of hospitals and/or practices, or method (b) - data provided by health insurance companies), there will be different algorithms used to estimate the total national frequencies of x-ray examinations, which will be prone to many potential sources of systematic and random (or statistical) error. These sources of error can lead to significant uncertainties in the frequency estimates and it is desirable, although often quite difficult, to identify and evaluate the major sources of uncertainty.

Important sources of uncertainty in the frequency estimates include:

- Problems in relating the information stored in terms of examination codes into actual numbers of examinations (e.g. inadequate definition of an “examination”, problems of double-counting, particularly with examinations of double-sided organs).

- Insufficiently differentiated codes (“accumulative codes”).

- Bias in the sample and invalid assumptions made when scaling up sample data to derive frequencies for the whole country (i.e. problem of using data from an unrepresentative sample of hospitals or from incomplete central statistics).

- Lack of frequency data from some important providers of radiology services (e.g. interventional procedures performed outside x-ray departments or fluoroscopy performed in operating theatres and therefore not recorded by the RIS, or dentists in private practice that are not covered by central statistics).

- Mistakes in the data recorded or collected.

All observations of x-ray examination frequency 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.

For example, if examination codes are insufficiently differentiated (i.e. the same code is used for different x-ray applications or for various body regions) a distribution has to be assumed in order to allocate an appropriate proportion of the examinations to certain body regions. Either a limited survey can be performed to estimate the distributions for these "accumulative codes" or experience from another country can be used or, most simply, an equal distribution between the different body regions could be assumed. A rough evaluation of the maximum likely uncertainty associated with each of these options should be possible, and then it is

necessary to assess the impact of these uncertainties on the overall result. The efforts taken to reduce this source of uncertainty need not be high if it has a low impact on the overall result. To find out if this is the case, an algorithm can be created in which all steps where uncertainties are introduced into the estimate of the overall result are included. By variation of the values of a particular uncertainty, the resultant total uncertainty estimates can be recorded and analysed. Uncertainties with high impact on the overall result need further attention. If resources are available, sample surveys can be conducted that focus on the identified problem. Alternatively, data from foreign countries with similar radiology practice can be taken into account.

Mammography is particularly prone to the problem of double-counting. The number of 'examinations' can be counted differently in different hospitals, sometimes as the number of breast examined and sometimes as the number of patients, often with one method applied to screening and the other to examinations of symptomatic patients. It is essential to know which method is being used in every hospital and to count an examination of both breasts on the same woman at the same time as one examination.

Some sources of random (or statistical) error cannot be avoided, but they can often be reduced. If, for example, frequency data are estimated by means of a sample survey, the statistical uncertainties can be minimized by optimization of the randomization process and by selecting an adequate sample size. If frequencies are derived from health insurance data, it is usually available at regular (annual) intervals. Therefore, time series of frequency data can be derived. On the one hand, time series enable one to recognise and correct mistakes in the data by comparing the figures for different years and amending those that appear to show inexplicable discontinuities. These mistakes may otherwise be difficult to recognise and are likely to be present in any of the frequency data, whether obtained by method (a) or (b). For example, simple typing errors can lead to mistakes in the recorded data or codes can be incorrectly interpreted and numbers assigned to the wrong type of examination. On the other hand, the assessment of time series of frequencies enables one to keep these uncertainties at least constant, and thus to recognise any trends in the frequency of x-ray examinations with time as early and as reliably as possible. This may be important from a regulatory point of view, or in order to identify examination types that are becoming of particular radiation protection relevance.

4 GUIDANCE ON ASSESSING PATIENT DOSES

In order to assess population exposures from medical radiology in terms of the collective or per caput effective dose it is necessary to estimate representative mean effective doses (E), for each type of x-ray examination that makes a significant contribution to the collective dose in a country.

Following the EC Medical Exposure Directive of 1997 [EC, 1997], most European countries have implemented national regulations requiring radiological installations to regularly assess patient doses to establish and check compliance with Diagnostic Reference Levels (DRLs). As a consequence, information on patient doses should now be readily available from significant numbers of hospitals and clinics around Europe, which will provide a useful source of patient dose data for population dose assessments. However, DRLs are not usually expressed in terms of effective dose, which cannot be measured directly in patients, but in terms of more easily measured patient dose quantities. Nonetheless, methods have been developed for converting these practical patient dose quantities into effective dose, using computational dosimetry techniques to model x-ray examinations on phantoms representing typical patients (see section 4.3).

Practical dosimetric quantities that are commonly measured include the entrance surface dose (ESD) or the dose-area product (DAP) for simple radiography, the dose-area product (DAP) for radiographic/fluoroscopic examination, and the computed tomography dose index (CTDI) and the dose-length product (DLP) for CT examinations. These practical dosimetric quantities and how to measure or calculate them are explained in more detail in section 4.1, with separate parts dealing with general radiography/fluoroscopy, mammography and computed tomography, respectively. Advice on the appropriate size and design of patient dose surveys to be sufficiently representative of national practice is given in section 4.2.

A number of radiation protection organisations around the world have published coefficients for converting the practical dose quantities into effective dose for a large number of types of x-ray examination under a wide range of exposure conditions. Section 4.3 explains how best to convert the measured doses into organ and effective doses using these published conversion coefficients.

In the case where a country is not able to make extensive patient dose measurements and to estimate nationally representative effective doses for all types of x-ray examination, it is usual practice to use published values from the literature, either from small local surveys in the same country or from surveys in other countries with similar healthcare settings (e.g. similar levels of education and training for radiographers and radiologists, similar provision of medical imaging equipment, etc.). Patient doses for the same examination are known to vary widely between countries and even between hospitals in the same country, so estimates of national mean doses based on just local or foreign data will not be very reliable. Ideally, such approximate methods should be used only for those types of examination which are not important contributors to the collective dose. However, for those countries currently without the resources to make extensive national patient dose surveys, three sets of ‘typical’ effective doses for those examinations making major contributions to collective dose, based on average values seen in the ten DOSE DATAMED countries are provided in section 4.4.

The likely impact of the 2007 recommendations of ICRP with a revised set of tissue weighting factors and the use of voxel phantoms for calculating effective dose is discussed in section 4.5. Finally some guidance on identifying uncertainties in patient dose estimates is provided in section 4.6.

It is highly recommended that medical physicists with particular expertise in the techniques of radiation dosimetry as applied to diagnostic radiology are directly involved in the assessment of patient doses for these population dose surveys.

4.1 How to measure or calculate practical patient dose quantities

International guidance on patient dosimetry techniques for x-rays used in medical imaging has recently been published by the International Commission on Radiation Units and Measurements in ICRU Report 74 [ICRU, 2005]. It contains a wealth of advice on the relevant dosimetric quantities and how to measure or calculate them in the clinical setting, which is directly applicable to the patient dose surveys needed to estimate population exposure from medical x-rays. We have drawn heavily on ICRU Report 74 in the following sections that describe suitable practical patient dose measurement methods for three areas of medical radiology with distinct dosimetric requirements - general radiography/fluoroscopy, mammography and computed tomography.

4.1.1 General radiography/fluoroscopy

The practical dosimetric quantities used in general radiographic and/or fluoroscopic x-ray examinations are listed and defined below. The names and definitions of these quantities are consistent with the recommendations in ICRU Report 74 but the names and abbreviations commonly used for them in the past are retained, along with the new ICRU symbols *[shown in square brackets]* which are used in the equations. Owing to the equivalence of numerical values of absorbed dose and kerma when expressed in the same units (J/kg) and measured in the same material for the x-ray energies used in medical imaging, the quantities are alternatively referred to in terms of absorbed dose (usually abbreviated to dose) or kerma. However, because almost all of these practical quantities will be measured with instruments calibrated in terms of air kerma, ICRU Report 74 names them only in terms of air kerma, except when they are measured or calculated inside a phantom or patient.

Absorbed Dose to air free-in-air and Incident Absorbed Dose
or Air Kerma free-in-air *[K_a]* and Incident Air Kerma *[$K_{a,i}$]*:

The absorbed dose to air (or the air kerma) measured free-in-air on the central axis of the x-ray beam at a specified distance, *d*, from the focus, or more specifically at the point where it enters the patient or phantom (at the focus skin distance, *FSD*), then called the Incident Absorbed Dose (or Incident Air Kerma, *[$K_{a,i}$]*). Neither of the quantities includes backscattered radiation and they are approximately related by the inverse-square law:

$$K_{a,i} = K_a(d)(d / d_{FSD})^2 \qquad \text{Units: mGy}$$

The air kerma free-in-air, K_a, measured at 1m distance (radiography) or 50cm distance (fluoroscopy) and normalized to the mAs product (tube current – exposure time product *[P_{It}]*) is often called the “dose yield” or “x-ray tube output” in units of mGy/mAs. According to the ICRU notation, ${}_nK_a = K_a / P_{It}$

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. If *B* is the backscatter factor:

$$K_{a,e} = K_{a,i} \cdot B \qquad \text{Units: mGy}$$

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

$$DAP = KAP = P_{KA} = \int_A K_a(A)\, dA \qquad \text{Units: Gy cm}^2$$

ESD or DAP can be used as the practical dose quantity for single radiographs. For more complex examinations consisting of a number of radiographs and/or fluoroscopy, the total DAP accumulated over the complete examination is the preferred quantity.

For examinations consisting of only a few radiographs, the ESD per radiograph for a representative average patient may be measured or calculated by the following methods:

- ESD may be measured directly on a sample of patients with a dosemeter attached to the patient's skin at the centre of the incident x-ray beam. Small dosemeters such as TLDs that do not interfere with the examination or obscure important diagnostic information on the radiographs are required. They should also be equally sensitive to radiation from all directions so as to fully measure backscattered as well as incident radiation. They need to be calibrated with respect to the radiation qualities used in diagnostic radiology. More detailed advice on the use and calibration of TLDs can be found in ICRU Report 74 [ICRU, 2005].

– ESD may be calculated from tube output measurements (mGy/mAs) made as a function of the exposure parameters (kV, filtration, focus size, etc) during routine Quality Control checks. The incident air kerma can be calculated from the tube output using the inverse square law and converted to the ESD by multiplying by the backscatter factor. Some x-ray equipment displays values of the air kerma free-in-air at a specified distance from the focus, calculated for the actual exposure parameters used (kV, filtration, focus size, mAs).

– If the tube output for the particular x-ray set is not known or cannot be measured, a more approximate estimate of the ESD can be obtained from published values of the x-ray tube output (mGy/mAs) as a function of the exposure parameters (tube voltage, filtration, etc) and appropriate backscatter factors for the field size used. Typical values for x-ray tube output and backscatter factors are shown in Table 8 [Martin & Sutton, 2000]. A more extensive list of backscatter factors can be found in Appendix A of ICRU Report 74.

Table 8: X-ray tube output, half-value layer (HVL) and backscatter factors as a function of tube voltage and filtration

	Typical values for 3 mm Al total tube filtration at the following tube voltages					
	60 kVp	70 kVp	80 kVp	90 kVp	100 kVp	120 kVp
Output (μGy/mAs at 1m)	46	61	78	96	115	155
Half-value layer (mm Al)	2.3	2.7	3.2	3.6	4.1	5.0
			Backscatter factor			
Field sizes:						
10 cm x 10 cm	1.27	1.29	1.30	1.33	1.37	1.42
15 cm x 15 cm	1.30	1.32	1.34	1.37	1.40	1.45
20 cm x 20 cm	1.31	1.33	1.35	1.38	1.41	1.46
30 cm x 30 cm	1.33	1.35	1.37	1.40	1.43	1.48

However, if a DAP meter is fitted to the x-ray set used for these simple radiographic examinations, it would be easier and just as effective to measure DAP rather than ESD in order to derive a mean effective dose (see section 4.3).

X-ray apparatus designed for more complex examinations consisting of several radiographs and/or fluoroscopy should be equipped with DAP meters to measure the total DAP accumulated over the complete examination, or a device for calculating and displaying the DAP values. DAP meters consist of transmission ionization chambers that are mounted on each x-ray tube between the diaphragms that control the beam size and the patient, so that their response is proportional to the beam area and the incident air kerma. They need to be calibrated in situ in order to correct for the under-couch or over-couch tube geometry, which will affect the relationship between the air kerma at the ionisation chamber and the incident air kerma to the patient. DAP meters have a degree of energy dependence and should be calibrated with a beam energy that lies midway between the range that will be met in practice. When using the mean value of DAP measurements made on a sample of 10-20 patients to derive a typical value, uncertainties due to the energy dependence of a DAP meter calibrated in this way will be small. More detailed advice on the use and calibration of DAP meters can be found in ICRU Report 74.

Most modern digital x-ray imaging equipment automatically calculates or measures patient doses in terms of practical dose quantities such as ESD or DAP for every patient examination and stores them as a part of the DICOM header. The possibilities for retrieving this digitally stored information to make patient dose surveys easier in the future are discussed in section 7.

4.1.2 Mammography

The only reason for wanting to estimate the effective dose in mammography is to complete the calculation of the total collective effective dose from all types of x-ray examination. For risk estimates in mammography it is far better to use the mean glandular tissue dose and age/sex-specific risk factors for radiation-induced breast cancer.

When calculating the effective dose from a mammography examination, it is reasonable to assume that the breast is the only exposed organ, so that only the dose to the radiosensitive

tissues in the breast and the tissue weighting factor for the breast need to be taken into account. The glandular tissues in the breast are considered to be the tissues at risk. The mean glandular dose (MGD) *[D_G]* can be calculated from the incident air kerma *[$K_{a,i}$]* by means of Monte Carlo based conversion factors provided for various radiation qualities (tube voltage, anode and filter material, and half value layer) and breast thicknesses and composition (percentage of glandular tissue and fat), according to the European Protocol on Dosimetry in Mammography [Zoetelief et al, 1996] or Appendix E of ICRU Report 74. When the purpose of the dose assessment is population dose estimation it is justified to use averaged values. The influence of different glandularity of the breast on the conversion factors is rather small: for commonly used beam qualities a change from 25% to 75% glandular tissue would correspond to a modification of the conversion coefficient of only ±10% about the value for 50% glandular tissue.

The coefficients for some typical exposure conditions (beam qualities) and breast thicknesses are shown in Table 9. They are derived from [Zoetelief et al, 1996].

Table 9: MDG/$K_{a,i}$ coefficients for some typical exposure conditions in mammography

Exposure conditions			HVL	MGD/$K_{a,i}$
Anode/filter	**Tube voltage**	**Breast thickness**	**(mm Al)**	**(mGy/mGy)**
Mo/Mo	28 kV	50 mm	0.32	0.173
Mo/Rh	28 kV	50 mm	0.4	0.210
Mo/Mo	28 kV	40 mm	0.32	0.207
Mo/Mo	28 kV	60 mm	0.32	0.135
Mo/Rh	28 kV	60 mm	0.4	0.172

The latest mammography units automatically provide calculated values of the MGD (in units of mGy) for all patients, according to this approach. Otherwise the incident air kerma can be measured with an ionization chamber as part of a quality control programme and can be converted to MGD according to well established protocols [Zoetelief et al, 1996]. If in a survey only $K_{a,i}$ is assessed for the individual exposures and not the breast thickness and beam quality, an average value for the conversion factor of 0.18 might be used. This will give a reasonable accuracy when the purpose is to assess the population dose from diagnostic procedures.

In the UK, the NHS Breast Screening Programme has published a software tool that automatically calculates mean glandular doses from information on the x-ray tube output, the exposure conditions and relevant patient parameters, according to the UK mammography dosimetry protocol [Dance et al. 2000]. It is freely available on the website of the UK National Co-ordination Centre for the Physics of Mammography [http://www.nccpm.org./NCCPM-patdose.htm], and is intended to standardize dose measurements and simplify procedures for national reviews of radiation doses in the NHS Breast Screening Programme. It might also be useful for national reviews of mammography doses in other countries where information on all the required patient and exposure parameters is available.

For conversion into an effective dose (see section 4.3) the MGD should be the average dose to the glandular tissue in both breasts. If only one breast is imaged during a mammography examination, the MGD to the exposed breast should be divided by two to obtain the MGD to the whole organ (both breasts).

4.1.3 Computed tomography

The practical dosimetric quantities used for CT examinations are listed and defined below. The names and abbreviations currently used are retained, along with the new ICRU Report 74 symbols *[shown in square brackets].* The definitions are also consistent with the valuable advice on CT dosimetry published in the Appendices of the European Guidelines for Multislice Computed Tomography [Bongartz et al, 2004].

CT Dose Index free-in-air ($CTDI_a$)
or CT Air Kerma Index free-in-air *[C_K]*:

$CTDI_a$ is the integral of the absorbed dose to air profile (or the air kerma profile *[C_K]*) along the axis of rotation of the CT scanner for a single rotation, divided by the product of the number of tomographic sections N and the nominal section thickness T (i.e. the beam collimation, mm). The CT dose index measured free-in-air with an ionization chamber of 100 mm length, is denoted by $CTDI_{100}$ *[or has the ICRU notation $C_{K,100}$]*

$$CTDI_a = C_K = \frac{1}{N \times T}\int_{-\infty}^{+\infty} K_a(z)dz \qquad CTDI_{100} = C_{K,100} = \frac{1}{N \times T}\int_{-50mm}^{+50mm} K_a(z)dz$$

Units: mGy

Weighted CT Dose Index in the standard CT dosimetry phantoms ($CTDI_W$)
or Weighted CT Air Kerma Index in the standard CT dosimetry phantoms *[$C_{K,PMMA,w}$]*:

The weighted CT dose (or air kerma) index is the weighted sum of the CT dose (or air kerma) index measured in the centre and periphery (1 cm under the surface) of a 16 cm diameter (head) or a 32 cm diameter (trunk) standard polymethylmethacrylate (PMMA) CT dosimetry phantom.

The CT dose index measured with a 100 mm long pencil ionization chamber inside a standard PMMA CT dosimetry phantom has the ICRU notation - $C_{K,PMMA,100}$.

$$C_{K,PMMA,100} = \int_{-50mm}^{+50mm} \frac{K_{a,PMMA}(z)dz}{N_i T_i} \qquad CTDI_w = C_{K,PMMA,w} = \frac{1}{3}\cdot C_{K,PMMA,100,c} + \frac{2}{3}\cdot C_{K,PMMA,100,p}$$

Units: mGy

The subscript *n* is used when the weighted CT dose or air kerma index is normalized to the mAs product (tube current multiplied with the tube rotation time), according to the ICRU terminology, ${}_nC_{K.PMMA,w} = C_{PMMA,w} / P_{It}$

Units: mGy/(mA.s)

Volume CT Dose Index ($CTDI_{vol}$):

The CT pitch factor for a scan sequence is the ratio of the distance moved (□d, 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).

$$\text{CT pitch factor} = \frac{\Delta d}{N \times T}$$

The pitch corrected value for the weighted CT dose (or air kerma) index, called the $CTDI_{VOL}$ is then calculated as:

$$CTDI_{vol} = CTDI_{w} / \text{CT pitch factor} = C_{K,PMMA,w} / \text{CT pitch factor}$$

Units: mGy

[NB. ICRU Report 74 does not recommend a special symbol for $CTDI_{vol}$]

CT dose-length product (DLP)
or CT air kerma-length product *[$P_{KL,CT}$]*:

CT dose (or air kerma)-length product depends on the $CTDI_{vol}$ and the axial length of the patient over which the CT examination is performed (L, cm).

DLP = $CTDI_{vol}$ x L Units: mGy cm

where for a particular scan sequence:
L is the scan length (cm) along the axis of the patient between the outer margins of the exposed volume, irrespective of the pitch (since the pitch is already taken account of in the $CTDI_{vol}$). For a helical scan sequence, L is the total scan length that is exposed during (raw) data acquisition, including any rotations at either end of the programmed scan length that are necessary for data interpolation.

Note that the DLP is derived from values of $CTDI_{vol}$ for **either** the standard head CT dosimetry phantom **or** the standard body CT dosimetry phantom. DLP's for different sequences are only additive if they refer to the same type of CT dosimetry phantom. Useful conversion factors have been established for relating estimates of DLP to effective dose for CT examinations of different regions of the body (see section 4.3).

Depending on the manufacturer's terminology, other equations may be useful for the calculation of the DLP:

For serial (axial) scanning: T_j is the single slice thickness and N_j the number of slices and P_{It} is the mAs product in serial scan number j	$DLP_{Axial} = P_{KL,CT} = \sum_{j} {}_{n} C_{K,PMMA,w_j} \cdot T_j \cdot N_j \cdot P_{It_j}$
For helical scanning: T_i is the nominal slice thickness (single slice) or the beam collimation (T_i=NxT for MSCT), I_i is the tube current and t_i the total acquisition time for the sequence i	$DLP_{Helical} = P_{KL,CT} = \sum_{i} {}_{n} C_{K,PMMA,w_i} \cdot T_i \cdot I_i \cdot t_i$

Values of the CT Dose Index in standard phantoms (centre and periphery) and for various scan fields of view (head and body, etc) are provided in the technical reference manuals from

the CT manufacturer, either given for clinically relevant scan techniques or normalized to a fixed mAs value. These values should be confirmed by measurements and calculations as part of the acceptance test by a medical physicist, and in further periodical status tests of the scanner. Furthermore, based on measured values at the factory for all optional tube voltages, scan fields of view (head, body, etc) and beam collimations, current models of CT scanners display values of $CTDI_{VOL}$ and the total DLP on the operator console at the end of the examination. The functionality and reliability of such options should also be tested and confirmed as a part of the acceptance test. If found acceptable, the displayed values of $CTDI_{VOL}$ and the total DLP provided by modern scanners may be recorded for use in population dose surveys. Since the dose values are now also defined as part of the DICOM header, it may be possible in the future to gather the data directly from the radiological information system (see section 7).

For older scanners, the following method may be used to calculate the $CTDI_{VOL}$ and the total DLP for a particular CT examination. For each scan sequence and for a particular scan field of view (head or body):

- Look up the values for the CT Dose Index (centre and periphery) in standard phantoms (16 or 32 cm) *[$C_{PMMA,100,C}$ and $C_{PMMA,100,p}$]* from the technical reference manual (or published elsewhere).
- Correct the values to the tube voltage actually used (look for modifying factors from 0.5 – 1.5 in the range 100 – 140 kV).
- Calculate the values for the mAs value actually used (mAs is the product of the actual tube current and the tube rotation time; there is a linear relation between CTDI and mAs).
- In helical scanning, study carefully the technical reference manual to identify the movement of the patient support (Δd, mm/360° rotation) and the beam collimation (NxT), in order to calculate and correct for the CT pitch factor. For increasing pitch values the $CTDI_{vol}$ will decrease, and vice versa.
- In sequential scan modes you should correspondingly correct for overlaps or gaps between slices.
- The CTDI is normalized to a certain beam collimation, for example 10mm. For narrower beam collimations, the CTDI will usually be somewhat higher. Such aperture adjustment factors may depend on the tube effect (kVxmA, kW) and the focus size.
- Calculate the CTDI in the centre and periphery separately according to the above modifying factors, and then calculate the $CTDI_{vol.}$
- Note that this value of the $CTDI_{vol}$ does not take any tube current modulation into account, unless you try to base it on some average mAs during the scan volume.
- DLP for each scan sequence is calculated as the product between $CTDI_{vol}$ and the scan length, which may be estimated with sufficient accuracy from the patient record (the scout view, reconstructed slice thickness, the number of images, etc.)

Alternatively, an extensive database of normalised CTDI values ($_nCTDI_a$ and $_nCTDI_W$) for a wide range of makes and models of CT scanner has been compiled by ImPACT – a CT scanner evaluation centre in the UK – and is freely available on their website [www.impactscan.org].

A CT examination may consist of several scan sequences with and/or without the use of intravenous contrast. The decision as to which parameters from a CT examination should be recorded, are discussed in section 4.2 on survey design.

4.2 Patient dose survey design

For practical reasons, patient dose surveys that are conducted to estimate the typical effective dose for each type of examination in a country have to be based on measurements or calculations of practical dose quantities at a limited number of hospitals, practices or clinics. Doses are known to vary widely between hospitals and even between individual radiology rooms or x-ray sets in the same hospital, so the typical national value is usually based on the mean of the radiology room mean dose values for a particular type of x-ray examination from as representative a sample of rooms and hospitals in a country as possible.

For example, Figure 4 illustrates the distribution in the mean effective dose for CT head scans over 47 CT scanner facilities in Norway in 1995 [Olerud, 1997]. The dose distribution reflects all kinds of CT manufacturer and model at the time of the survey, different use of scan parameters, various numbers of scan series (use of contrast agents) and different clinical indications for head CT (although all considered to be "typical" at each scanner site). The mean effective doses for CT head scans are seen to range over a factor of 8 across the 47 scanner sites. Recent technical developments with high speed multi-detector CT are likely to increase this variation in clinical practice even further.

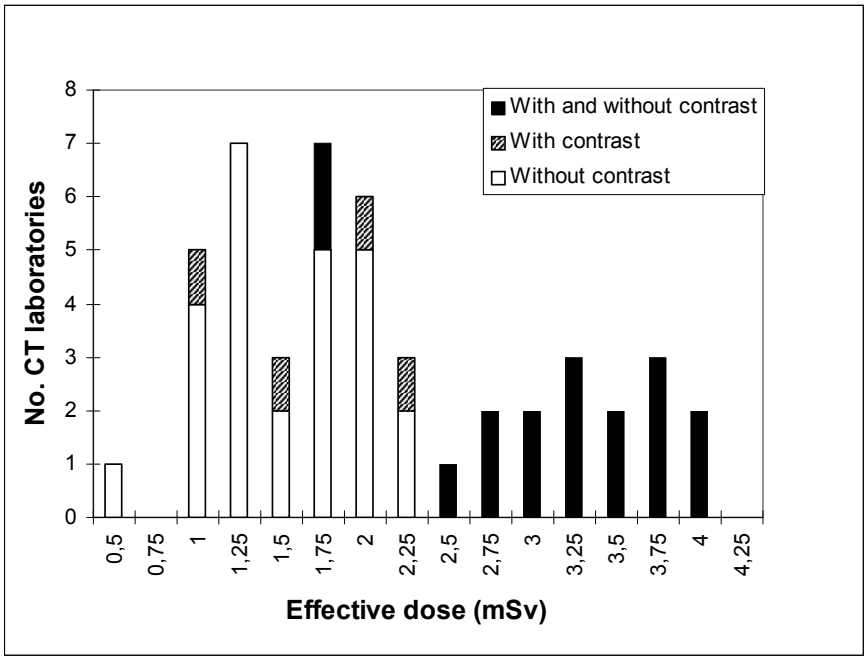

Figure 4: Distribution in mean E for CT head scans between 47 CT facilities in Norway in 1995

Because of this wide distribution in mean doses, the design of a patient dose survey, particularly with regard to its size and coverage, is of crucial importance to limit the uncertainty in the estimated representative or typical average dose for each examination type. Consequently, attention should be paid to the following points:

- The number of hospitals and clinics included in the survey must be large enough to reflect all variations in clinical practice in the country; i.e. variations in the use of equipment, radiographic technique, exposure parameters, contrast agents, etc.

- The number of rooms included from each hospital and the selection of hospitals must be such that they reflect all types of x-ray equipment used for a certain examination type in the country (e.g. covering the age and technology).
- When measuring doses directly on patients, the sample of patients in each room/facility should be representative regarding their size (weight) and the clinical indication. Ideally doses should be measured or calculated for at least 10 and preferably 20 close-to-average size adult patients (e.g. with weights between 60–80 kg) and no complication leading to higher than usual doses or no premature termination of the examination should have occurred.
- When doses are measured or calculated for a standard examination protocol, be certain that the protocol is representative for the average "typical" procedure used in each room/facility for average sized adult patients. Ideally investigate all protocols used in a room/facility to identify the average clinical practice.

Particular attention should be given to the justification and optimisation of x-ray examinations on children. Their increased sensitivity for radiation-induced cancer and their longer life expectancy will lead to the more probable manifestation of late radiation effects compared to adults. However, for the purpose of making population dose estimates, it is reasonable to assume that children receive the same mean effective dose as adults from the same type of examination. When exposure factors are selected to suit the smaller sizes of paediatric patients and to maintain the same dose to the image receptor, entrance surface doses will be smaller than for adults but will be attenuated less to reach organs at depth, resulting in similar effective doses. Also, so few children are x-rayed in comparison with adults that any small differences in the effective doses for children compared to adults will have an insignificant effect on the total collective dose. For this reason, patient dose surveys designed to determine mean effective doses for use in population dose estimates can concentrate on adult patients only, as described above.

Most patient dose surveys for CT are based on collecting information about the typical examination protocols used for a number of types of CT examination in each CT facility, together with measured or displayed values of CTDI and DLP if these are available. If not the CT facility staff can be asked to complete a questionnaire giving details of all the scan parameters used for each type of CT examination, from which typical values for the practical dose quantities are derived by the competent authority or institution that is conducting the national dose survey. The values of DLP are then converted into effective doses using the methods discussed in section 4.3. There are, however, considerable difficulties in designing the questionnaire so that it can be easily and reliably completed by the CT facility staff and correctly interpreted by those performing the effective dose calculations. Some of the most important difficulties are discussed below:

- The manufacturers change the names of the scanner models almost every year, and models purchased a few years ago can be updated to perform like new models by simple software changes. It is important that the local staff know exactly what 'model' their CT scanner performs like.
- Different hospitals and CT facilities might have a different understanding of CT examination terminology. For example, what is a "typical" CT examination of the lumbar spine; does it include the sacrum or not? What is a typical abdominal CT examination;

does it include the pelvis? It would help if the questionnaire listed common clinical indications for each type of CT examination for which typical scan parameters were being requested.

- Diagrams of the body for drawing the outlines of the scanned volume should be a part of the questionnaire. The diagrams may be quite simple, just showing important anatomical landmarks such as the eyes, the boundaries of lungs, liver, pelvis, etc. The questionnaire should also ask for the typical scan length in cm for the particular protocol on an average sized patient, and the number of scan sequences, with or without use of intravenous contrast.
- The questionnaires should be designed and explained so that hospitals supply complete information. Different manufacturers have different terminology, which may be confusing for the local staff and for the national centres that receive all the information. For example, is the $CTDI_W$ corrected for the pitch or not? If using tube current modulation, what does the $CTDI_W$ value refer to (some average)? Is the quoted mAs value the simple product of tube current and rotation time, or is it some kind of “effective mAs” (corrected for the pitch value). And what about the pitch value? The definition may vary between single and multi-slice scanners. This also applies to the meaning of slice thickness. We have no need for the reconstructed image slice thickness in dose calculations. It is not always obvious what the beam collimation (total active detector length in the z-direction) really is either. All these elements require that those who are going to do the dose calculations will have to know the scanner models closely to sort out any misunderstanding at the local hospital.

Extracts from a recent UK CT Dose Survey Questionnaire [Shrimpton et al, 2005] are shown in Appendix 2, which incorporate many of the above suggestions for collecting the required information for routine CT examinations of the head and the abdomen.

4.3 How to convert practical dose quantities into effective doses

The effective dose E is defined by ICRP [ICRP, 1991, 2007a] as the weighted sum of the mean doses to a number of radiosensitive tissues or organs in the body. ICRP Publication 60 specifies 12 tissues or organs with reasonably well established sensitivities for the stochastic effects of radiation and a further 10 (the so-called ‘remainder organs’) which might be susceptible to cancer induction but with a lower and individually undetermined sensitivity. Ideally estimates of the mean absorbed dose to each of the 12 specified organs and to as many of the remainder organs as possible are required to estimate the effective dose. Since it is impossible to make direct measurements of most of these organ doses in living patients, it has been common practice to resort to the use of computational dosimetry techniques to model x-ray examinations on phantoms representing typical patients. All the organs for which dose estimates are required, need to be replicated in the phantoms as well as the intervening and surrounding tissues that will attenuate and scatter the x-ray beam.

Most of the computational dosimetry techniques use Monte Carlo radiation transport codes to simulate medical x-ray exposures on the phantoms and to calculate the energy deposited in each organ. Once suitable computer programs have been developed to perform these calculations, they can be readily repeated to simulate a whole series of medical x-ray examinations and provide coefficients relating organ doses and the effective dose to the practical dose quantities discussed in section 4.1 that can be easily measured in the x-ray

beam outside the patient or calculated from the appropriate exposure parameters. A number of radiation protection organisations around the world have performed these Monte Carlo calculations and have published organ and effective dose coefficients for a large number of types of x-ray examination under a wide range of exposure conditions [Rosenstein 1992, Stern 1995, Drexler 1990, Zankl 1991, Jones 1991, Jones 1993, Hart 1994a, Hart 1994b, Hart 1996a, Hart 1996b, Tapiovaara 1997]. Detailed descriptions of the scope and content of the handbooks and reports produced by four organisations (CDRH, GSF, HPA/NRPB, and STUK), including sample tabulations of organ dose conversion coefficients, can be found in Appendices B, C, D and F of ICRU Report 74.

For population dose assessments, mean values of the measured or calculated practical dose quantity for a nationally representative sample of patients can be 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 can be derived for each type of x-ray examination, which can be combined with information on the frequency of each type of examination to obtain the collective effective dose.

In their recent surveys of population exposure from medical x-rays most of the DOSE DATAMED countries used effective dose coefficients developed by NRPB, but some used coefficients developed at GSF, Germany and at STUK, Finland (i.e. PCXMC). 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 four Monte Carlo codes. Published comparisons of these four sets of Monte Carlo conversion coefficients have shown sufficient agreement with each other not to invalidate comparisons of the effective doses calculated in different countries using different sets of Monte Carlo coefficients. Consequently any of these four sets of conversion coefficients can be used to estimate effective doses for x-ray examinations. The set which most closely matches the exposure conditions and examination techniques for the examinations in question should be used, if possible.

However, the NRPB coefficients are available for a larger number of x-ray examinations (radiographic/fluoroscopic and CT) and exposure conditions than any of the others, and they have been used to derive generalised effective dose coefficients for most of the top 20 exams, using typical exposure factors and examination techniques seen in the UK survey. If it is not possible to derive conversion coefficients matched specifically to the exposure factors and examination techniques used in a particular country, it is recommended that these generalised coefficients may be used.

4.3.1 General radiography/fluoroscopy

Generalised coefficients in terms of E/DAP for the radiographic/fluoroscopic examinations that contribute most to the collective dose are shown in Table 10. They have been derived from [Hart et al, 1994a].

Table 10: Generalised E/DAP coefficients for radiographic/fluoroscopic examinations

Exam type	E/DAP (mSv/Gy cm^2)
1. Chest (PA + Lat) High kV Chest (PA + Lat) Low kV	0.18 0.10
2. Cervical spine	
3. Thoracic spine	0.19
4. Lumbar spine	0.21
6. Abdomen	0.26
7. Pelvis & hip	0.29
8. Ba meal	0.2
9. Ba enema	0.28
10. Ba follow	0.22
11. IVU	0.18
12. Cardiac angio.	0.2

4.3.2 Mammography

As discussed in 4.1.2, for conversion into an effective dose the MGD should be the average dose to the glandular tissue in both breasts. If only one breast is imaged during a mammography examination the MGD to the exposed breast should be divided by two to obtain the MGD to the whole organ (both breasts).

To convert the MGD to both breasts into effective dose, it should be multiplied by the ICRP tissue weighting factor for the breast (0.05 according to ICRP, 1991) with no allowance made for the fact that the tissue weighting factor is averaged over both sexes but only women usually undergo mammography.

The conversion factors between the incident air kerma $K_{a,I}$ and the MGD for some typical exposure conditions in mammography were shown in Table 9. The corresponding conversion factors between effective dose and the incident air kerma are shown in Table 11 for the situation when only one breast is exposed and when both breasts are exposed.

Table 11: $E/K_{a,i}$ coefficients for some typical exposure conditions in mammography

Exposure conditions			HVL (mm Al)	$E/K_{a,i}$ (mSv/mGy)	
Anode/filter	**Tube voltage**	**Breast thickness**		**One breast exposed**	**Both breasts exposed**
Mo/Mo	28 kV	50 mm	0.32	0.0043	0.0087
Mo/Rh	28 kV	50 mm	0.4	0.0053	0.011
Mo/Mo	28 kV	40 mm	0.32	0.0052	0.010
Mo/Mo	28 kV	60 mm	0.32	0.0034	0.0068
Mo/Rh	28 kV	60 mm	0.4	0.0043	0.0086

If in a survey only $K_{a,i}$ is assessed for the individual exposures and not the breast thickness and beam quality, an average value for the conversion factor of 0.005 for one breast exposed and 0.009 for two breasts exposed might be used. These will give a reasonable accuracy when the purpose is to assess the population dose from diagnostic procedures.

4.3.3 Computed tomography

Generalised coefficients for CT examinations in terms of E/DLP are shown in Table 12.
They are taken from Table 4 in Appendix C of the European Guidelines for Multislice Computed Tomography [Bongartz et al, 2004]. This Table provides typical E/DLP values for different regions of the body and the European Guidelines recommend that they can be used with any type and model of CT scanner.

Table 12: Generalised E/DLP coefficients for CT examinations

Region of body scanned	E/DLP (mSv/mGy cm)
13. Head	0.0021
14. Neck	0.0059
15. Chest	0.014
17. Abdomen & pelvis	0.015
18. Pelvis	0.015
19. Trunk	0.015

Special software programs are also available for converting CTDI and DLP measurements into effective dose for different makes and models of CT scanner and for a variety of scan regions and scan lengths. These are available on the websites of the Impact group in the UK [http://www.impactscan.org/] and CT-Expo group in Germany [http://www.mh-hannover.de/1604.html] and have been regularly updated in the past for new scanners coming onto the market. However, the latest set of generalised E/DLP coefficients shown in Table 12 have been recommended by the European Guidelines Working Party as providing a more elegant and simpler framework for the assessment of patient doses for all types of CT scanner.

4.4 Typical effective doses for the 'Top 20 exams'

The mean effective doses for each of the 'Top 20 Exams' were seen to vary very widely between the ten DOSE DATAMED countries, as shown in section 9.2.4 of DD Report 1 and reproduced below in Table 13. The ratio of the maximum to the minimum dose is shown in the last column of the Table and whereas for most examinations it lies between factors of 2-5, occasionally it exceeds a factor of 10.

Table 13: Mean effective doses for the 'Top 20 Exams' in the ten DOSE DATAMED countries

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

This wide diversity between countries means that for reliable population dose estimates it is preferable to use patient dose data that has been obtained from a representative number of hospitals and clinics in the country in question. However, for those countries currently without the resources to make extensive national patient dose surveys, three sets of 'typical' effective doses for the 'Top 20 Exams' are provided in Table 14.

The three sets are based on the mean values seen in three different groups of the ten DOSE DATAMED countries representing:

1. A higher exposure group (Germany and Switzerland)
2. An average exposure group (All ten countries)
3. A lower exposure group (Netherlands and United Kingdom)

The dose data from Germany, Switzerland, the Netherlands and the United Kingdom all comes from relatively large surveys that were fairly representative of national practice at the time of the survey. The mean effective doses in Germany and Switzerland were consistently higher than those seen in the Netherlands and the UK. For the radiographic and fluoroscopic examinations (1-12) they were mostly higher by factors of 2-10, but for the CT examinations (13-19) and for PTCA (20) they were mostly higher by only 20-60%. There are also some differences in the healthcare settings between the countries in the higher exposure group

and the lower exposure group (e.g. levels of education and training for radiographers and radiologists, levels of provision of medical imaging equipment, levels of involvement of medical physics experts in radiology, etc.) which might have an influence on the exposures per examination.

It is suggested that those countries which have to resort to using these sets of typical effective doses should choose the set that is derived from countries in which the healthcare setting most closely matches their own. More details about the healthcare settings in the ten DOSE DATAMED countries can be found in section 5 of DD Report 1.

Table 14: Mean effective doses for the 'Top 20 exams' depending on exposure level group

Exam type	Mean E per examination (mSv)		
	Higher exposure group *(DE, CH)*	**Average exposure group *(All 10)***	**Lower exposure group *(NL, UK)***
1. Chest/thorax	0.25	0.10	0.03
2. Cervical spine	0.70	0.27	0.04
3. Thoracic spine	2.00	1.00	0.40
4. Lumbar spine	2.80	1.90	0.50
5. Mammography	0.40	0.33	0.25
6. Abdomen	1.80	1.50	0.50
7. Pelvis & hip	1.35	0.90	0.45
8. Ba meal	15.00	7.70	2.60
9. Ba enema	12.50	8.60	6.40
10. Ba follow	24.50	10.00	4.40
11. IVU	3.50	4.00	2.60
12. Cardiac angio.	11.25	9.10	5.30
All Angiography	***8.60***	***9.20***	***7.30***
13. CT head	2.40	2.00	1.60
14. CT neck	2.80	2.50	2.40
15. CT chest	8.20	8.00	6.60
16. CT spine	6.00	5.30	3.60
17. CT abdomen	13.50	12.00	10.20
18. CT pelvis	8.80	8.70	8.70
19. CT trunk	24.40	14.00	10.40
All CT	***7.05***	***6.10***	***5.35***
20. PTCA	17.00	14.00	13.15
All Interventional	***15.35***	***10.70***	***6.50***

Detailed descriptions of these 'Top 20 exams', including some common clinical indications for the examinations and commonly used imaging techniques are given in Appendix 1.

4.5 New Developments in calculating effective dose.

Revised tissue weighting factors

The recommended tissue weighting factors for effective dose will change with the publication of the new Recommendations of ICRP in 2007 [ICRP Publication 103, 2007a]. The old [ICRP Publication 60, 1991] and new tissue weighting factors are compared in Table 15. In particular the weighting factor for the gonads has decreased by over a factor of two, and the

weighting factor for the breasts and the remainder organs has increased by over a factor of two. Furthermore organs have been introduced that did not formerly have weighting factors, such as the salivary glands, the extrathoracic region, the oral mucosa and the prostate (the last three now being included in the remainder tissues).

In the 2007 recommendations there are 14 remainder organs and the splitting rule that was applied to remainder organs in the 1990 recommendations is no longer used.

Table 15: Tissue weighting factors according to ICRP 1990 and 2007 recommendations

Organ or tissue	ICRP Tissue Weighting Factors		
	1990	2007	2007/1990
Gonads	0.20	0.08	0.4
Bone marrow	0.12	0.12	1.0
Lower large intestine	0.12	0.12	1.0
Lung	0.12	0.12	1.0
Stomach	0.12	0.12	1.0
Bladder	0.05	0.04	0.8
Breast	0.05	0.12	2.4
Liver	0.05	0.04	0.8
Oesophagus	0.05	0.04	0.8
Thyroid	0.05	0.04	0.8
Bone surface	0.01	0.01	1.0
Skin	0.01	0.01	1.0
Brain	In remainder	0.01	(0.4)
Salivary glands	0	0.01	∞
Remainder organs*	0.05	0.12	2.4

* 1990 = adrenals, brain, kidney, muscle, pancreas, small intestine, spleen, thymus, upper large intestine, uterus
2007 = adrenals, extrathoracic region, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate, small intestine, spleen, thymus, uterus

There are now two organs in the head with specific tissue weighting factors of 0.01 (brain and salivary glands) and two more remainder organs in the region of the head (extrathoracic region and oral mucosa) each sharing 1/14 of the remainder organs' tissue weighting factor of 0.12. This has interesting implications for medical x-ray exposures that only irradiate the head, such as CT head scans and skull radiography. Previously the brain was the only recognised radiosensitive organ in the head (apart from a small fraction of the bone and bone marrow for which the tissue weighting factors have not changed). According to the splitting rule the brain was previously given half the remainder organ weighting factor (0.025). Under the 2007 recommendations, there are now four recognised radiosensitive organs in the head region with a total weighting factor of nearly 0.04. Effective doses for x-ray examinations of the head are consequently likely to be significantly higher under the new recommendations.

Effective doses for medical exposures of the chest region are also likely to be higher because of the increased weighting factor for the breast. For most x-ray examinations of the chest the breast is only one of a number of radiosensitive organs that will be irradiated (e.g. lung, liver, oesophagus, thyroid) so the increase in effective dose will be small. This will not be the case, of course, for mammography, where no other organ receives a significant dose and so the effective dose will be more than doubled. This increase in effective dose for mammography is unfortunate, since the increased risk of radiation-induced breast cancer is very age-dependent being almost entirely concentrated in girls under the age of 20, who do not usually undergo mammography examinations. This demonstrates the inappropriateness

of using effective dose rather than the mean glandular tissue dose and specific age-dependent risk factors when estimating radiation-induced breast cancer risks.

Effective doses for medical exposures of the pelvic region will be significantly lower because of the large reduction in the weighting factor for the gonads (the introduction of the prostate as a remainder organ will be cancelled out by the small reduction in the weighting factor for the bladder). Effective doses for x-ray examinations of the abdomen are likely to remain substantially the same.

In summary, it would appear that the new tissue weighting factors might result in significant increases in effective doses calculated for x-ray examinations of the head (and inappropriately for mammography) and significant reductions for examinations of the pelvis. Consequently, care must be taken when comparing new and old effective dose estimates, not to confuse changes due to the use of different tissue weighting factors with changes due to differences in radiology practice.

New voxel phantoms

It has been common practice to derive organ and effective doses for medical x-ray exposures using Monte Carlo radiation transport codes to simulate x-ray examinations on phantoms representing typical patients (see section 4.3). In the past, the phantoms have been based on those developed at the Oak Ridge National Laboratory in the USA, originally for internal dosimetry calculations (the MIRD phantoms), which represent the necessary organs and tissues in the body as simple geometrical volumes of appropriate size, shape and position. Recently more realistic tomographic or 'voxel' (volume pixel) phantoms have been developed based on whole body CT or MRI scans of real patients. Body contours and tissue and organ boundaries can be more accurately modelled from these scan data than with the simple geometric shapes of the earlier mathematical phantoms.

A series of 'reference' voxel phantoms for male and female adults and children are currently being developed for ICRP, in order to provide improved organ and effective dose conversion coefficients for public and occupational exposures. In the near future it is likely that similar sets of improved conversion coefficients will be developed for diagnostic medical exposures based on these reference voxel phantoms [Zankl, 2002]. They will undoubtedly provide improved accuracy over the mathematical phantoms used in the past for estimating typical organ and effective doses to patients. However, care must be taken when comparing new and old effective dose estimates, not to confuse changes due to the use of different phantoms with changes due to differences in radiology practice.

4.6 Identifying uncertainties in patient dose estimates

Estimates of the typical effective dose for each type of examination in a country are usually based on measurements of practical dose quantities at a limited number of hospitals or clinics and conversion of these measurements to effective doses (see section 4.3). The important sources of uncertainty in these estimates include:

- Uncertainties in the basic dose measurements
- Uncertainties due to variations in patient doses between hospitals and the limited sample size.

- Uncertainties in the coefficients used to convert the measured dose quantities into typical effective doses

Uncertainties in basic dose measurements

ICRU Report 74 [ICRU, 2005] 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 and in practice uncertainties of about 10-20% are more likely to apply to individual basic dose measurements.

However, 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, include the uncertainties in the dose measurements themselves.

Uncertainties due to variations in patient doses between hospitals and the limited sample size

Estimates of the typical effective dose for each type of examination in a country are usually based on measurements of practical dose quantities 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 in the estimated mean value 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 databases of this type in Europe [Hart and Wall, 2002]. These random uncertainties were derived from the standard errors on the mean (SEOM) of the radiology room mean dose values, which will increase as the number of rooms (n) where measurements were made decreases (SEOM = standard deviation / $\sqrt{n}$). Approximate uncertainties in the estimated mean value at the 95% confidence level (set at rounded values of twice the SEOM) are shown in Table 16 as a function of sample size.

Table 16: Random uncertainties in estimated mean doses for x-ray examinations as a function of sample size

Sample size	SEOM (%)	Random uncertainty (95% confidence level)
> 100 rooms	4.4 (3.3-6.0)*	±10%
20-100 rooms	13 (10-18)*	±25%
5-19 rooms	23 (10-30)*	±50%

* Numbers in brackets indicate range over at least 7 types of x-ray examination

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 with regard to patient doses, it is usually not possible to quantify this source of uncertainty, but it should be low if all reasonable steps have been taken to ensure as random and as large a sample of hospitals and rooms as possible.

For small countries where the sample sizes in the Table above approach (or even exceed) the total number of radiology rooms in the country, the uncertainties from this source of random error will be much smaller (or even zero).

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 than those shown in Table 16. A general 95% confidence limit of about 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 are based on measurements in >20 radiology rooms.

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 (see section 4.3). 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 phantoms used in the Monte Carlo calculations of the conversion coefficients discussed in section 4.3, are very similar in all 4 sets of Monte Carlo calculations and closely match 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, 2007]. 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%.

It should be mentioned here that the exposure conditions for certain types of examination can vary considerably between or even within countries. For example, conventional chest examinations may be performed with a high or a low tube voltage technique, resulting in a difference of nearly a factor of two in the E/DAP conversion coefficients (see Table 10). It is consequently very important to use conversion coefficients that were derived under exposure conditions that match clinical practice in a particular country as closely as possible, to reduce this source of uncertainty to a minimum.

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. by summing the uncertainties in quadrature). 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 Table 17.

Table 17: Overall uncertainties in mean effective dose estimates as a function of sample size and matching of exposure conditions for conversion coefficients

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

5 GUIDANCE ON ASSESSING AGE/SEX DISTRIBUTIONS OF X-RAY PATIENTS

Due to the wide variation in radiation risks with age at exposure and sex, it is of interest to determine how the frequency of and doses from medical x-ray examinations are distributed by sex and age within the population. Representative data on age/sex distributions for a number of common x-ray examinations were available from five of the DOSE DATAMED countries. The data were divided into five year age bands for each sex and thus provided more detailed information than the UNSCEAR reports which reported age and sex distribution in terms of just three broad age bands (0-15 years, 16-40 years, >40 years) for both sexes combined [UNSCEAR, 1993 and 2000]. The higher level of resolution for patient age/sex data that is available from the five DOSE DATAMED countries is considered desirable for use with the assessments of age/sex specific radiation risks discussed in section 2.

The data from the five countries were compared to see if they were sufficiently similar to justify combining them to provide typical European patient age/sex distributions for those examinations making important contributions to the population dose. These could then be used by those countries that do not have specific national data readily available. The five countries were Luxembourg, Denmark, the Netherlands, Switzerland and the UK. The size of the samples of patients for which age and sex data were available for each of the 'Top 20 exams' in each country is shown in Table 18.

TABLE 18: Sample sizes for age/sex data in five DOSE DATAMED countries

Top 20 Exam	Numbers of patients in sample (male & female)				
	Luxembourg	**Denmark**	**Netherlands**	**Switzerland**	**UK**
Chest	74873	640695	695668	14426	82930
Cervical spine	12815	42136	65187	2123	---
Thoracic spine	7915	44105	34533	1125	---
Lumbar spine	25138	105152	119817	50	6611
Mammography	23523	107614	98264	4427	---
Abdomen	8880	29551	88066	1623	12998
Pelvis	29612	203461	181886	3729	9196
Ba meal	2396	1999	11182	146	---
Ba enema	889	9620	32080	143	3084
Ba follow	207	7986	---	99	---
IVU	4029	16760	16097	463	1640
Cardiac angio.	1545	26322	9039	50	1233
CT head	19795	90116	65509	848	7001
CT neck	3451	3734	---	157	---
CT chest	6035	50450	31076	591	2678
CT spine	13356	14386	17818	638	---
CT abdomen	11879*	78346	46338	868	2303
CT pelvis	---	21731	4275	98	1922
CT trunk	1279	100077	---	---	---
PTCA	698	---	2402	50	---

* includes CT pelvis

There were ten examinations (out of the 'Top 20 exams') for which all five countries had data**.** For 6 more of the 'Top 20 Exams' there were age/sex data from four of the five countries, for another 3 there were data from 3 countries, and for CT trunk examinations there were data from only 2 countries.

The age/sex distributions were plotted for each country, each examination and each gender in 5-year age bins. Example distributions are shown in Figures 5-8 for male IVU and lumbar spine examinations and for female barium enema and CT chest examinations respectively. It can be seen that the distributions are sufficiently similar between the five countries to justify taking the average as a reasonable guide to typical practice in Europe and for use when specific national data are not available.

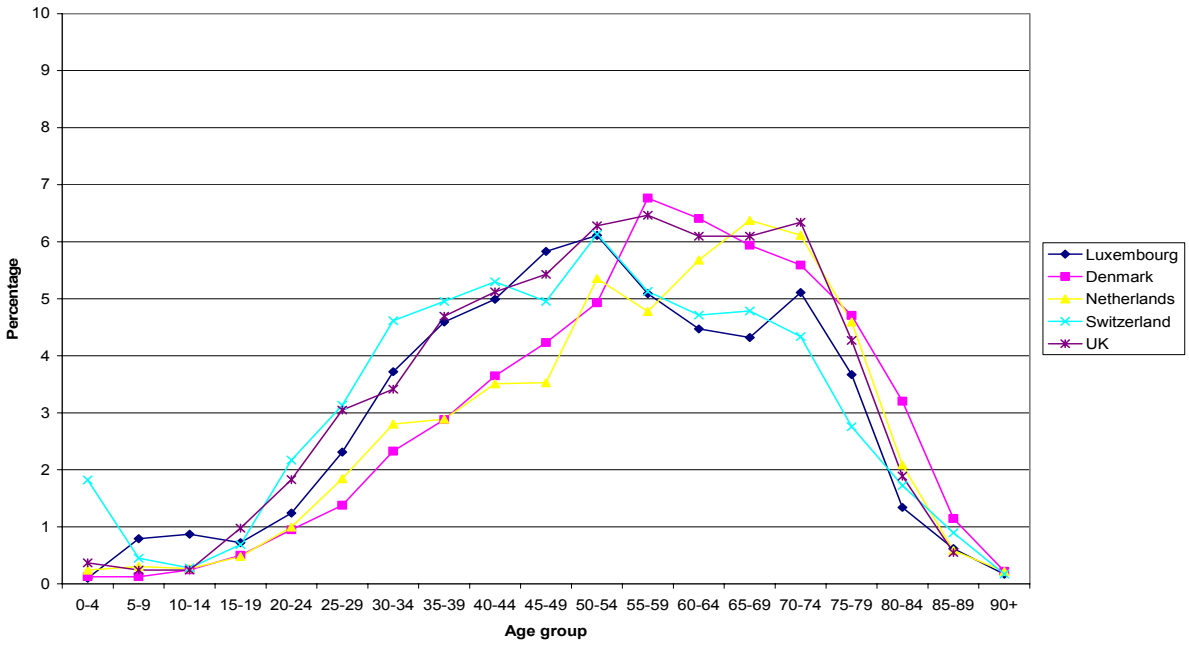

Figure 5: Age distributions for IVU exams on males from 5 countries

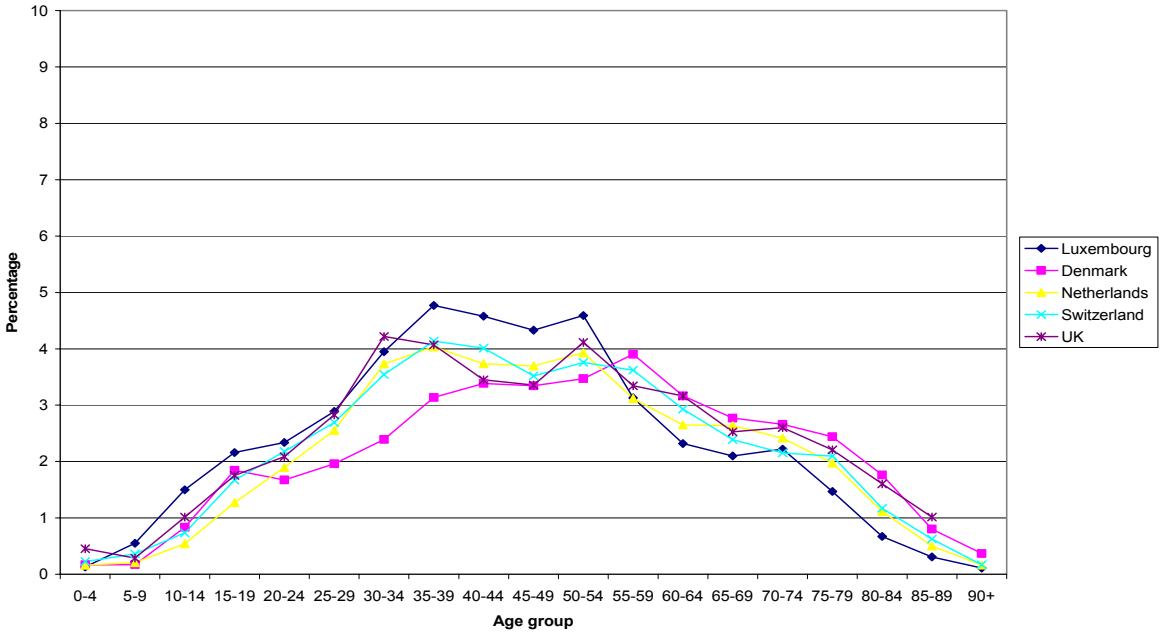

Figure 6: Age distributions for lumbar spine exams on males from 5 countries

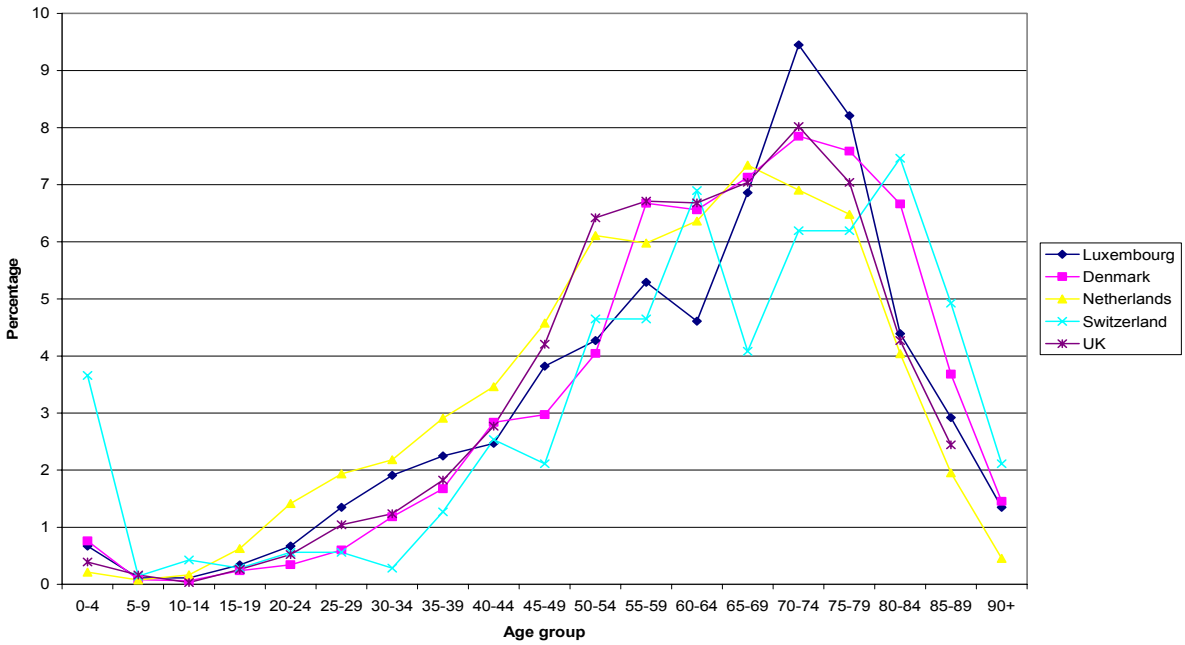

Figure 7: Age distributions for barium enema exams on females from 5 countries

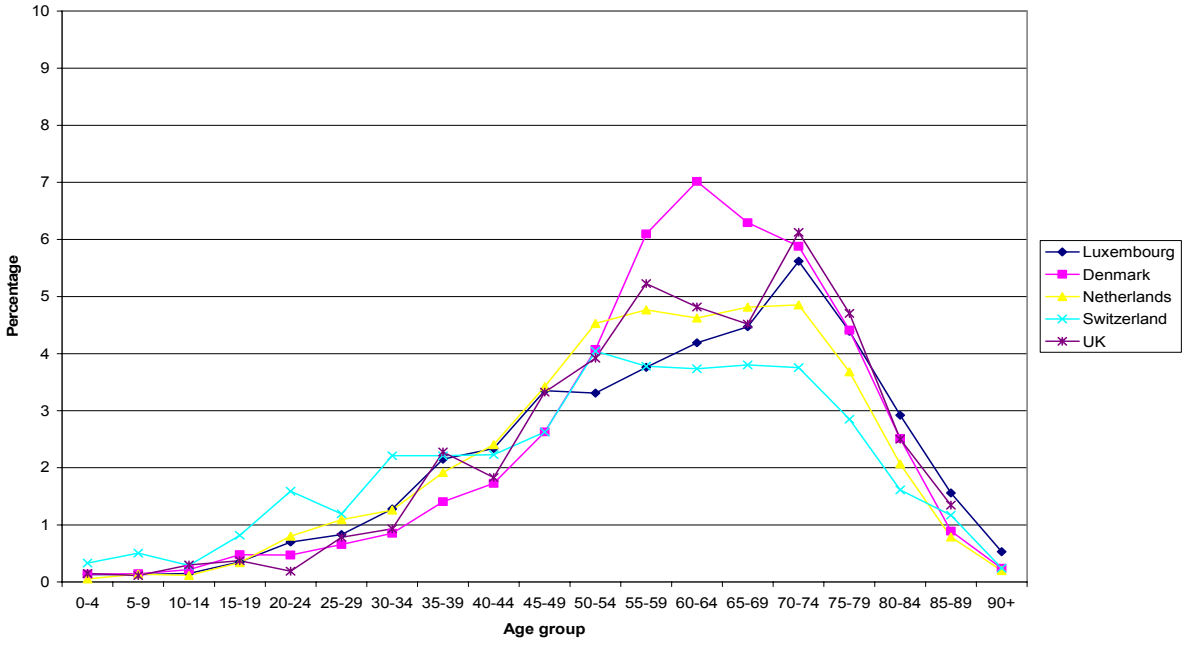

Figure 8: Age distributions for CT chest exams on females from 5 countries

However, it would not be appropriate to establish typical European age/sex distributions for patients undergoing specific x-ray examinations if the demographics of the whole population differed markedly from country to country. The age distributions of the whole population (both sexes combined) for each of the 10 countries involved in the DOSE DATAMED project are compared in Figure 9, which is derived from data in the US Census Bureau's international database [www.census.gov/ipc/www/idbnew.html]. It can be seen that all the countries have a roughly similar distribution, peaking between the ages of 35-45 years and falling fairly

consistently thereafter. These national population distributions would appear to be sufficiently similar to justify the use of typical average x-ray patient age/sex distributions that can be applied to any European country.

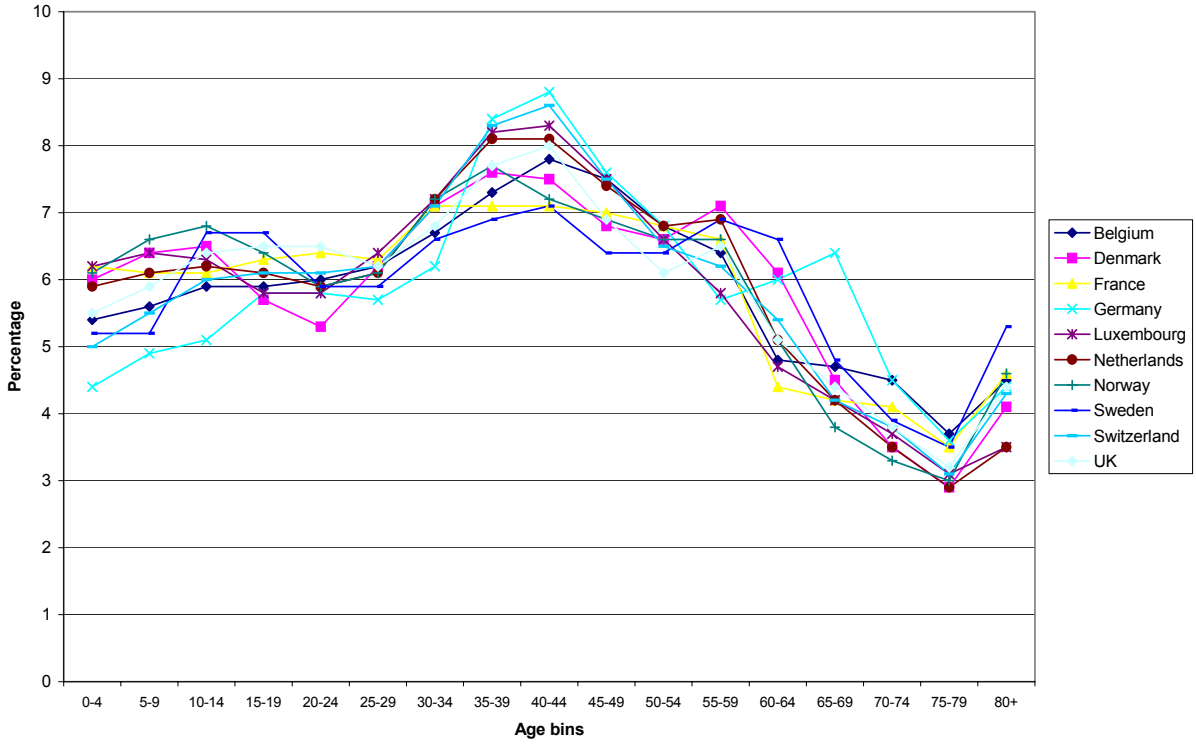

Figure 9: Population age distributions in the ten DOSE DATAMED countries (2005)

Typical European age/sex data for the 'Top 20 Exams' and for 'All CT, 'All angiography' and 'All interventional' procedures, based on the average distributions seen in these five DOSE DATAMED countries are shown in Appendix 3.

It is suggested that these can provide a useful guide to the age and sex distributions for these important types and categories of examination that can be used by any European country to relate collective doses to collective detriment, in the absence of more reliable national data. The breakdown of the data into five year age bins for each sex is considered to be more useful for this purpose than the three broad age bands previously reported by UNSCEAR.

6 GUIDANCE ON PRESENTING THE RESULTS OF POPULATION DOSE ESTIMATES

This section describes a harmonised way of presenting the results of population dose estimates that have been made according to the methods described in the previous sections.

Firstly, the objectives of the study need to be clearly stated in any report on population doses from medical radiology. These might include all or only some of the six objectives listed in section 2, and any additional objectives specifically related to the management of radiology practice in a particular country. If objective 6 or any additional objectives that involve comparisons of the radiation risks from medical radiology with those from other sources of population exposure are being considered, the serious limitations of collective effective dose in this regard (as discussed in section 2) should be declared. In this case, information on the age and sex distributions of patients undergoing x-ray procedures that are important contributors to the collective dose would be useful.

Whatever the objectives, in view of the rapid developments currently taking place in medical radiology with significant new clinical applications for x-ray imaging appearing every year, it is important that their impact on population exposure is kept under regular review. It is therefore recommended that, if possible:

- Frequency surveys should be repeated every 5 years.
- Patient dose surveys should be repeated every 5 years.
- Both types of survey should be as close in time as possible.

Although it is recognised that the resources required to perform these surveys are considerable (see section 2) and not every country may be able to meet this ideal.

The information that is considered to be essential to report in a population dose survey is listed below, followed by other information that is considered to be highly desirable if the available resources allow.

Essential information to report:

Total annual collective effective dose from all medical x-ray imaging procedures
Total annual average per caput effective dose from all medical x-ray imaging procedures

Total annual numbers of all medical x-ray imaging procedures
Total annual numbers of all medical x-ray imaging procedures per 1000 population

Annual average per caput effective dose from:

- All CT examinations.
- All angiographic examinations.
- All interventional procedures.
- All radiographic and fluoroscopic diagnostic x-ray examinations not included in above 3 categories.

Annual numbers per 1000 population of:

- All CT examinations.
- All angiographic examinations.

- All interventional procedures.
- All radiographic and fluoroscopic diagnostic x-ray examinations not included in above 3 categories.

Mean effective dose per procedure for:
- All CT examinations.
- All angiographic examinations.
- All interventional procedures.
- All radiographic and fluoroscopic diagnostic x-ray examinations not included in above 3 categories.

To make reasonable estimates for all the above information it is essential, at least, to identify those diagnostic examinations and interventional procedures making the major contributions to the total collective dose. Those responsible for at least 75% of the collective dose should be listed together with their percentage contribution to the total frequency and the total collective dose and the mean effective dose estimated for each examination/procedure. If a country does not have the resources to investigate and identify the procedures that are currently responsible for 75% of the collective dose, the 'Top 20 Exams' listed in Table 6 (and described in detail in Appendix 1) can be used.

It should be clearly stated whether the above information covers all significant types of radiology practice in the country or not. For example, is nuclear medicine or dental radiology included?

The actual years (dates) that the patient dose data and the examination frequency data relate to should be clearly stated.

Desirable information to report:
If the relevant frequency and/or patient dose data are available, the 4th category above ('All radiographic and fluoroscopic diagnostic x-ray examinations') should be further divided into:
- Radiography of the teeth;
- Radiography of the chest;
- Radiography of the limbs;
- Radiography of the spine;
- Mammography;
- Radiography/fluoroscopy of the gastro-intestinal tract;
- Radiography/fluoroscopy of the urinary tract;
- Other radiography/fluoroscopy.

Collective dose, frequency and mean dose data for these broad groupings (together with the 'All CT', 'All angiographic' and 'All interventional' categories listed above) are desirable in order to provide a reasonably complete description of the situation in a particular country and to assess and elucidate differences between countries. They probably represent the 'lowest common denominator' for the frequency and dose data available in most European countries.

The age and sex distributions of the patients undergoing those examinations and procedures making major contributors to the collective dose should ideally be determined from a representative sample of patients in the country. If this is not possible, the typical European age/sex distributions shown in Appendix 3, based on the average distributions seen in the

DOSE DATAMED countries can be referred to. This information is particularly desirable if any objectives that involve comparisons of the radiation risks from medical radiology with those from other sources of population exposure are being considered.

7 USE OF ELECTRONIC INFORMATION AUTOMATICALLY STORED IN MODERN MEDICAL IMAGING SYSTEMS AND RADIOLOGY INFORMATION SYSTEMS

To comply with Article 12 of the Medical Exposure Directive [EC, 1997], it is necessary to estimate individual doses from medical exposures and to determine their distribution for the population and for relevant reference groups of the population. So there is an obligation on Member States that data related to the radiation doses delivered to patients by medical x-ray procedures must be collected and archived. Most modern digital x-ray equipment is capable of calculating or measuring patient doses in terms of practical dose quantities such as ESD or DAP (conventional x-ray) or CTDI and DLP (CT scanners) for every patient examination and storing them as a part of the so-called 'DICOM header' that is associated with every digitally stored image (DICOM = Digital Imaging and Communications in Medicine). Retrieval of this digitally stored information should make patient dose surveys easier in the future.

The goal of the DICOM Standard is to achieve compatibility and improve workflow efficiency between imaging systems and other information systems in healthcare environments worldwide.

Radiological information is currently stored in a hierarchy of information systems:
- Picture Archiving and Communication Systems (PACS).
- Radiological Information Systems (RIS).
- Hospital Information Systems (HIS).
- Electronic Patient Journals (EPJ).

X-ray technology is rapidly progressing towards digital image registration in all European countries. It would obviously be convenient for the x-ray users if patient dose information could run into the RIS and be regarded as a part of the electronic patient journal (EPJ). Dose data together with other relevant information might then be gathered from these systems more or less automatically. To do this, all these systems must be able to communicate with each other. There are at least six RIS/PACS manufacturers and even more producers of x-ray equipment currently supplying the European market. A particular component in a certain system may be a part of more than one producer's portfolio. This means that there is a complex system of components acting together, and different producers may have different terminology and different ways of solving the same problem. The need for standardisation therefore has to be urgently addressed both by the producers of x-ray equipment and the RIS/PACS manufacturers.

Modern medical x-ray imaging equipment has the capability of measuring or estimating one or more relevant dosimetric quantities and of being DICOM compatible. To facilitate the implementation of patient radiation dose reporting, DICOM and the IEC (International Electro-technical Commission) have during the last few years undertaken work to introduce a template for diagnostic x-ray dose reporting into the DICOM standard [DICOM 2006]. They have proposed a new structured report (SR), which will facilitate the flow and management of data relating to patient doses. Currently (December 2007), a 'Radiation Dose Report' exists for conventional x-ray procedures (radiography/fluoroscopy) and one is close to completion for CT.

Nevertheless, although standards exist, it is not yet possible for the user to acquire the dose data easily, since the amount and the format of the information available depends very much on the x-ray device, the manufacturer, etc. One way to improve the situation would be to involve IHE (Integrating the Healthcare Enterprise).

IHE results from an initiative in 1999 between the Radiological Society of North America (RSNA) and the Healthcare Information and Management Systems Society (HIMSS) to improve the way that computer systems in healthcare share information. IHE promotes the coordinated use of established standards such as DICOM to address specific clinical needs in support of optimal patient care. Systems developed in accordance with IHE communicate with one another better, are easier to implement, and enable healthcare providers to use information more effectively.

Consequently, a new proposal for an IHE profile in radiology was submitted by IHE France (in a joint action of the French Society of Radiology - SFR and the Institute for Radiation Protection and Nuclear Safety - IRSN) to IHE international. The 'Radiation Dose Profile' proposal [IHE, 2007] was accepted at the international level in November 2007 and will be further developed during 2008.

Examples of patient dose and other relevant information required

All x-ray based medical imaging modalities use the various practical dose quantities discussed in section 4.1 for reporting patient dose information after an examination, either from calculated figures or measured values. In conventional x-ray examinations, including angiography, there is the dose free in air at a certain distance, entrance surface dose (ESD) or the dose-area product (DAP). In mammography there is the mean glandular tissue dose (calculated); while in computed tomography there is the CT dose index measured in one of two special CT dosimetry phantoms, weighted and corrected for the pitch ($CTDI_{vol}$), and the dose-length product (DLP). The various dose quantities (ESD, DAP, $CTDI_{vol}$ or DLP) are not directly comparable, but each one provides a relative indication of the dose associated with the specific examination. The dose information needed to estimate the 'patient dose' is at least one of these dosimetric quantities, which are easy to monitor and are also required for the establishment of national reference levels [EC, 1997].

It will be up to the standardization committees of IEC, DICOM and the IHE to specify in more detail how these dose data (and other important data from the examination that are needed for assessments of collective effective dose) should be stored and exchanged. The following list is provided to illustrate the complexity in the examinations and the choices that have to be made:

In conventional X-ray (radiographs and fluoroscopy):

- No of exposures (radiographs).
- Per radiographic projection (mentioned by name).
    - Tube voltage (kV).
    - Tube current and exposure time (mAs).
    - Field size at image receptor.
    - Dose free in air at certain distance (mGy).
    - ESD (mGy).
- Total Fluoroscopy time (min).
- Dose-area Product (DAP) for the complete examination (mGy cm^2).

In computed tomography (CT):

- No of CT scan sequences (with and without intravenous contrast).
- Scan length (cm) along the axis of the patient between the outer margins of the exposed volume, irrespective of pitch (ideally with some anatomical landmarks).
- The scan field of view (SFOV).
- Per CT scan sequence.
    - Tube voltage (kV).
    - Tube current (mA).
    - Tube rotation time (s).
    - Beam collimation.
    - Table speed.
    - Pitch.
    - $CTDI_{vol}$ (pitch corrected weighted CT Dose Index) (mean value in the volume if using tube current modulation).
- Dose-length product (DLP) for the complete examination (mGy cm).
- Free text comments.

In Mammography:

- No of projections.
- Per breast and radiographic projection (mentioned by name).
    - Mean glandular dose (mGy).

Recommendations

Most modern x-ray imaging systems have the capability to produce patient dose reports, but not yet in a standard DICOM format. When the new IEC standard and IHE profile come into operation and are accepted by all manufacturers of x-ray imaging equipment, and recognized by the RIS manufacturers, it should considerably ease the burden of making patient dose surveys. The x-ray users (hospitals, radiology institutes, etc) should include conditions about the new IEC standard and the IHE profile in their requirement specifications when purchasing new x-ray equipment or new RIS/PACS systems. X-ray equipment manufacturers and RIS suppliers will then have to affiliate to the IHE profile if they want to survive in the market.

The suggested dose parameters to be stored in the DICOM header and transferred to the RIS also provide the basis for calculation of the effective dose. Health authorities may consequently gather information from the user's RIS, as input to any national dose databases for the establishment of diagnostic reference levels and for future population dose estimates. Some countries may even regard it necessary to revise their national legislation to

sanction the right to ask for this dose information by law and to recognise the organisation that would be the competent authority to perform population dose estimates, as required by the Medical Exposure Directive.

8 SUMMARY OF RECOMMENDATIONS

8.1 Purposes of population dose estimates, desired frequency and resources required

- Any report on population doses from medical radiology should clearly state the objectives of the study. These might include all or only some of the following objectives:
    1. To observe trends in the annual collective dose (or the annual average per caput 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 collective dose from all medical x-rays.
    3. To determine the relationship between the frequencies of different types of x-ray examination, the typical radiation doses given to patients and their contribution to the total collective 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 frequencies and the annual per caput doses from medical x-rays between countries.
    6. To compare the contribution from medical x-rays with those from other natural and man-made sources of population exposure in a country.
    7. To determine the age and sex distribution of the patients undergoing specific types of x-ray examination, particularly those making a major contribution to the total collective dose.

- If objective 6 or any additional objectives that involve comparisons of the radiation risks from medical radiology with those from other sources of population exposure are being considered, the serious limitations of collective effective dose in this regard (as discussed in section 2) should be declared and objective 7 is particularly important.

- It is recommended that, if possible:
    - Frequency surveys should be repeated every 5 years.
    - Patient dose surveys should be repeated every 5 years.
    - Both types of survey should be as close in time as possible.

  although it is recognised that the resources required to perform these surveys are considerable (see section 2) and not every country may be able to meet this ideal.

- At least two senior scientists, should be responsible for co-ordinating the whole project and to assure the scientific quality of the results

- The team conducting the survey should have expertise (internally or by external consultancy) in radiology, dosimetry, public health, statistics and project management.

- National public health and the radiation protection authorities should be involved in the project.

- Collaboration with the professional bodies associated with medical radiology is essential from the first stage of the survey.

8.2 Suitable dose quantities

- The annual collective and per caput effective doses for the totality of all x-ray examinations conducted in a country and for those specific examinations making major contributions to the total should be estimated, to meet objectives 1-5.

- In addition, information on the age and sex distribution of the patients undergoing the types of x-ray examination making a major contribution to the total collective dose will be valuable for relating the collective doses to the collective detriment (important for objective 6).

- Effective dose estimates for medical exposures should **not** be used for assessing radiation risks to patients by simple application of ICRP's nominal probability coefficients for radiation-induced cancer.

8.3 Guidance on assessing frequency of x-ray examinations

- An x-ray examination or interventional procedure should be defined as:
  'O*ne or a series of x-ray exposures of one anatomical region/organ/organ system, using a single imaging modality (i.e. radiography/fluoroscopy or CT), needed to answer a specific diagnostic problem or clinical question, during one visit to the radiology department, hospital or clinic'*.

- The most reliable and accurate approach is to collect frequency data (and estimate typical effective doses) for all 225 specific types of examination listed in the 2nd column of Tables 2-5.

- The second best approach is to collect frequencies (and estimate doses) for the 70 categories of examinations listed in the 3rd column of Tables 2-5.

- The third best approach is to give priority to the examination types and categories that contribute most to the collective effective dose in the country, covering at least 75% of the total. If a country does not have the resources to investigate and identify the procedures that are currently responsible for 75% of the collective dose, the 'Top 20 Exams' listed in Table 6 (and described in detail in Appendix 1) can be used.

- Annual numbers of examinations can be obtained directly from a sample of hospitals, clinics or practices and then scaled up to cover the whole country; or from central statistics held by government departments or insurance companies for all (or at least a large proportion) of radiology practice in the country.

- Information on the annual numbers of x-ray examinations should be available from the computerised Radiology Information Systems (RIS) that are now widely in place in most hospitals throughout Europe.

- 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 radiology practice as possible.

- It is important to make clear whether dental radiology conducted by dentists in 'Dental Practices' and/or Nuclear Medicine examinations are included in the population dose assessments or not.

- Major sources of error in the frequency estimates should be identified and the uncertainties evaluated. Important sources of uncertainty include:
    - Problems in relating the information stored in terms of examination codes into actual numbers of examinations.
    - Bias in the sample and invalid assumptions made when scaling up sample data to derive frequencies for the whole country.
    - Lack of frequency data from some important providers of radiology services
    - Mistakes in the data recorded or collected.

8.4 Guidance on assessing patient doses

- Medical physicists with particular expertise in diagnostic radiology dosimetry should be directly involved in the assessment of patient doses.

- In order to assess population exposures from medical radiology in terms of the collective or per caput effective dose it is necessary to estimate representative mean effective doses (E), for each type of x-ray examination that makes a significant contribution to the collective dose in a country.

- The most reliable and accurate approach is to conduct extensive patient dose surveys to measure or calculate practical dose quantities at as representative a sample of hospitals in a country as possible.

- The practical dose quantities that are commonly measured include the entrance surface dose (ESD) or the dose-area product (DAP) for simple radiography, the incident air kerma (K_{ai}) for mammography, the dose-area product (DAP) for radiographic/fluoroscopic examinations, and the computed tomography dose index (CTDI) and the dose-length product (DLP) for CT examinations.

- The number of hospitals and clinics included in the survey must be large enough to reflect all variations in clinical practice in the country.

- The number of rooms included from each hospital and the selection of hospitals must be such that they reflect all types of x-ray equipment used for a certain examination type in the country.

- For the purpose of making population dose estimates, it is reasonable to assume that children receive the same mean effective dose as adults from the same type of examination.

- When measuring doses directly on patients, the sample of patients in each room/facility should be representative regarding their size (weight) and the clinical indication. Ideally doses should be measured or calculated for at least 10 and preferably 20 close-to-average size adult patients (e.g. with weights between 60–80 kg). No complication leading to higher than usual doses or no premature termination of the examination should have occurred.

- When doses are measured or calculated for a standard examination protocol, the protocol should be representative for the average "typical" procedure used in each room/facility for average sized adult patients.

- When selecting coefficients for converting practical dose measurements into effective doses, those which most closely match the exposure conditions and examination techniques for the examinations in question should be used.

- If it is not possible to derive conversion coefficients matched specifically to the exposure factors and examination techniques used in a particular country, the generalised coefficients shown in Tables 10-12 may be used.

- For those countries currently without the resources to make extensive national patient dose surveys, three sets of 'typical' effective doses for the 'Top 20 Exams' are provided in Table 14. Such countries should choose the set that is derived from the DOSE DATAMED countries in which the healthcare setting most closely matches their own.

- Major sources of error in the typical effective dose estimates should be identified and the uncertainties evaluated. Important sources of uncertainty include:
    - Uncertainties in the basic dose measurements.
    - Uncertainties due to variations in patient doses between hospitals and the limited sample size.
    - Uncertainties in the coefficients used to convert the measured dose quantities into typical effective doses.

- The new tissue weighting factors recommended in the 2007 recommendations of the ICRP are likely to result in significant increases in effective doses calculated for x-ray examinations of the head and breast and significant reductions for examinations of the pelvis. Consequently, care must be taken when comparing new and old effective dose estimates, not to confuse changes due to the use of different tissue weighting factors with changes due to differences in radiology practice.

- In the future when voxel phantoms are used to derive improved organ and effective dose conversion coefficients for diagnostic medical exposures, care must be taken when comparing new and old effective dose estimates, not to confuse changes due to the use of different phantoms with changes due to differences in radiology practice.

8.5 Guidance on assessing age/sex distributions of x-ray patients

- When the objectives of making a population dose estimate include comparisons of the contribution from medical x-rays with those from other natural and man-made sources of population exposure in a country, it is important to determine the age and sex distribution of the patients undergoing important types of x-ray examination.

- Ideally, the age and sex distribution of patients undergoing those types of x-ray examination making a major contribution to collective dose should be determined in each country by a representative survey of national practice.

- Ideally, the data for each type of examination should be presented in five year age bins for each sex.

- If specific national data are unavailable, typical European age/sex data for the 'Top 20 Exams' and for 'All CT, 'All angiography' and 'All interventional' procedures, based on the average distributions seen in five DOSE DATAMED countries, can be used. These are shown in Appendix 3.

8.6 Guidance on presenting the results of population dose estimates

- Clearly state the objectives of the study, the period over which data was collected and whether it covers all significant types of radiology practice in the country or not.

- Essential information to report:
  - Total annual collective effective dose from all medical x-ray imaging procedures.
  - Total annual average per caput effective dose from all medical x-ray imaging procedures
  - Total annual numbers of all medical x-ray imaging procedures.
  - Total annual numbers of all medical x-ray imaging procedures per 1000 population.
  - Mean effective dose per procedure (averaged over all medical x-ray imaging procedures).

  - Same data as above but broken down into:
    - All CT examinations.
    - All angiographic examinations.
    - All interventional procedures.
    - All radiographic and fluoroscopic diagnostic x-ray examinations not included in above 3 categories.

  - List those types of examination or procedure responsible for at least 75% of the collective dose.
  - Give percentage contribution to the total frequency and the total collective dose and the mean effective dose estimated for each of these examinations/procedures.
    If a country does not have the resources to investigate and identify the procedures that are currently responsible for 75% of the collective dose, the 'Top 20 Exams' listed in Table 6 (and described in detail in Appendix 1) can be used.

- Desirable information to report:
  - Same data as above but 4th category further divided into:
    - Radiography of the teeth.
    - Radiography of the chest.
    - Radiography of the limbs.
    - Radiography of the spine.
    - Mammography.
    - Radiography/fluoroscopy of the gastro-intestinal tract.
    - Radiography/fluoroscopy of the urinary tract.
    - Other radiography/fluoroscopy.

  - Ideally, the age/sex distributions of the patients undergoing the major contributors to the collective dose should be determined from a representative sample of patients in the country.
  - If this is not possible, the typical European age/sex distributions shown in Appendix 3, based on the average distributions seen in the DOSE DATAMED countries can be referred to.

8.7 Use of electronic information stored in modern medical imaging and radiology information systems

- The need for compliance with the latest IEC standards and IHE profiles for radiation dose reporting in radiology should be included in purchasing specifications for new x-ray equipment or new RIS/PACS systems.

- In the future the national authorities responsible population dose surveys may gather the electronic information on patient doses from RIS/PACS systems around the country as input to any national dose databases for the establishment of diagnostic reference levels and/or for future population dose estimates.

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10 APPENDIX 1

Detailed Examination Descriptions for 'Top 20 Exams'

Detailed descriptions of the 20 types of examination that were consistently found to be amongst the highest contributors to the collective effective dose in the ten DOSE DATAMED countries (the 'Top 20 Exams' as discussed in section 3.1 of this report), are provided in the following Tables according to imaging modality:

Table A1.1 PLAIN FILM RADIOGRAPHY (without contrast media)

Table A1.2 RADIOGRAPHY/FLUOROSCOPY (mostly involving use of contrast media)

Table A1.3 COMPUTED TOMOGRAPHY

Table A1.4 INTERVENTIONAL PROCEDURES

The details include a list of the specific examinations to be included in each of the 20 examination types, an outline of the common examination techniques employed and a list of clinical indications for which the examination type is most commonly used. These details are based on guidance published by the French Society of Radiology (SFR) and the Institute of Radiation Protection and Nuclear Safety (IRSN) in 2001 [1] and on the referral guidelines published by the UK Royal College of Radiologists in 2003 [2], which take into account European as well as UK practice.

It is hoped that these detailed descriptions of the 'Top 20 Exams' will help those countries that adopt this approach for assessing population exposures to make the most appropriate selection of examinations to include in their assessments. The validity of future comparisons of radiology practice and population exposures between European countries will also be improved by adopting these clear definitions and descriptions of the important examinations.

References

[1] SFR and IRSN, 2001. Les Procedures Radiologiques: Criteres de Qualite et Optimisation des Doses. http://pagesperso-orange.fr/eassa.cordo/SFROPRI/index.htm

[2] RCR, 2003. Making the Best Use of a Department of Clinical Radiology – Guidelines for Doctors (Royal College of Radiologists, London).

Table A1.1 PLAIN FILM RADIOGRAPHY (without contrast media)

Exam Type	Specific exams included in 'Exam type'	Common Technique	Common indications
1. Chest/lung	Lungs & ribs Thoracic inlet	PA radiograph LAT radiograph	Adult pneumonia, chest pain, pericarditis, pleural effusion, pneumothorax. A LAT is taken after PA **only if** necessary to locate a pulmonary nodule or a hilar projection shadow more precisely
2. Cervical spine	Cervical spine	AP & LAT/Oblique radiographs	Trauma, cervical pain/neuralgia
3. Thoracic spine	Thoracic spine	AP & LAT radiographs	Trauma, interscapular back pain
4. Lumbar spine	Lumbar spine Lumbo-sacral joint Sacro-iliac joints Sacrum & coccyx	AP & LAT radiographs	Trauma, lumbar pain, sciatica, cauda equina syndrome
5. Mammography	Symptomatic & Screening	Medio-lateral oblique &/or Cranio-caudal radiographs on one or both breasts	Breast cancer screening, breast cancer symptomatic patients
6. Abdomen	Abdomen (plain film)	AP radiograph	Acute abdominal pain, monitoring occlusive syndromes
7. Pelvis & hip	Pelvis (one or both hips)	AP radiograph or AP & LAT radiographs	Trauma, rheumatology, dysplasia

Table A1.2 RADIOGRAPHY/FLUOROSCOPY (mostly involving use of contrast media)

Exam Type	Specific exams included in 'Exam type'	Common Technique	Common indications
8. Ba meal	Ba meal (stomach & duodenum)	2-3 minutes fluoroscopy 5-20 images	Preoperative analysis for certain stomach lesions and for postoperative monitoring after gastric and oesophageal surgery
9. Ba enema	Ba enema (colon)	~2 minutes fluoroscopy 5-10 images	Inflammation, suspected tumour, control after surgery and for occlusive syndromes
10. Ba follow	Ba follow (small intestine) Small bowel enema	~5 minutes fluoroscopy 5-20 images	Small bowel disease (e.g. Crohn's disease, malabsorption syndromes)
11. IVU (Intravenous Urography)	IVU (kidneys, ureter and bladder)	Several AP radiographs after IV injection of iodine contrast medium	Haematuria, renal colic, infection of urinary organs, dilation of excretory organs, unexplained backache, urological tumour
12. Cardiac angiography	Coronary angiography Left or right ventriculography	~5 minutes fluoroscopy Several hundred images	Atheromatous arterial disease or coronary anomaly, spastic angina. Systolic or diastolic dysfunction. Mitral, tricuspid, aortic or pulmonary valve dysfunction.

Table A1.3 COMPUTED TOMOGRAPHY

Exam Type	Specific exams included in 'Exam type'	Common Technique	Examples for indications
13. CT head	Head, brain, facial bones	With or without contrast	Brain lesion, acute stroke. Chronic rhinosinusitis, nasal obstruction, nasosinusitis polyposis, anosmia. Facial trauma. Chronic inflammation of middle ear, petrosal bone trauma. Congenital malformations.
14. CT neck	Soft tissue in neck, cervical spine	No contrast	Trauma, cervical pain/neuralgia, medullary compression syndrome, extra- or intra-spinal tumors
15. CT chest	Chest/thorax	With or without contrast Std or High resolution	Mediastinal/pleural/pulmonary pathology. Diffuse infiltrative lung disease, bronchial diseases, lung cancer
16. CT spine	CT of lumbosacral spine	With or without contrast	Trauma, lumbar pain, lumboradiculalgia, sciatica, cauda equina syndrome
17. CT abdomen	Abdominal organs	With or without contrast	Cancer diagnosis and staging, infectious lesions, inflammatory diseases, major trauma. Acute abdominal pain. Suspected haemorrhage. Chronic hepatic illness, liver metastases or suspected obstruction of hepatic vessels.
18. CT pelvis	Pelvic bone &/or organs	With or without contrast	Cancer diagnosis and staging, location of stones/lesions/tumours resulting in obstruction of urinary channels. Suspected extrinsic compression or malformation of the urinary channels. Pelvimetry
19. CT trunk	CT of chest, abdomen & pelvis. CT of thoracic/ abdominal aorta	With or without contrast With contrast	Metastases from unknown primary tumour, lymphoma, trauma. Thoracic/abdominal aorta disease: aneurysm, occlusion, dissection, inflammation, embolism, malformation.

Table A1.4 INTERVENTIONAL PROCEDURES

Exam Type	Specific exams included in 'Exam Type'	Common Technique	Examples for indications
20. Coronary angioplasty (PTCA)	PTCA	Catheter access via femoral or brachial artery, balloon inflation at constriction, stenting may be performed	Angina or painless myocardial ischemia in relation to one or several coronary lesions. Acute myocardial infarction.

11 APPENDIX 2

EXTRACTS FROM

UK CT DOSE SURVEY QUESTIONNAIRE

(Shrimpton et al, 2005)*

1. Survey Instructions
2. Routine head scan
3. Abdomen scan

References

* Shrimpton PC, Hillier MC, Lewis MA, Dunn M. (2005) Doses from Computed Tomography CT) Examinations in the UK – 2003 Review. NRPB-W67 (NRPB, Chilton).

Survey Instructions

Overview

There are three aspects to data collection for the UK CT dose survey, with specific forms in separate sections of this questionnaire:

Section One – Survey of routine protocols
The protocol survey is being conducted to obtain information on the routine protocols used on each scanner for some common indications and a standard patient. You need only provide data for those examination/ indication categories shown on the forms.

Section Two – Survey of individual patients
The patient survey aims to gather information on the actual scan sequences used for an individual patient, since these may differ from the standard protocol according to particular clinical needs. For each of the particular combinations of examination and clinical indication shown, forms should be completed for ideally at least 10 patients. We require recent data from your archive for adult patients who are close to average size (excluding those who are excessively small or large) and for children (please indicate age in years). Please use the 'Form No.' field, if you wish, to help when collecting your data for 10 patients. We appreciate that collation and submission of these data might necessarily follow on behind sending us your information on standard protocols. It is hoped that such data collection for individual patients will become an ongoing exercise.

Section Three – CTDI measurements for your particular scanner
Any local measurements that you can provide for your scanner will be useful as a check when assessing your doses. However, submission of CTDI data is optional and may be done separately from your protocol and individual patient questionnaires.

Explanation of fields on forms

The following paragraphs are provided as a guide to completion of the forms.

1. Examination/ indication

   There are separate forms for each of 12 scanning procedures on different anatomical regions and patient groups. It is important that you only provide information on each form in relation to the specific examination and indication shown, in order to allow subsequent comparison with similar data from different centres.

2. Manufacturer, model and hospital.

   Include as much detail on the model as possible since this may affect the scanner dosimetry. A list of most scanner models installed in the UK is provided in Appendix 1. Please use these descriptions in full when completing the forms. If your scanner is not included in the list, please provide the full model name.

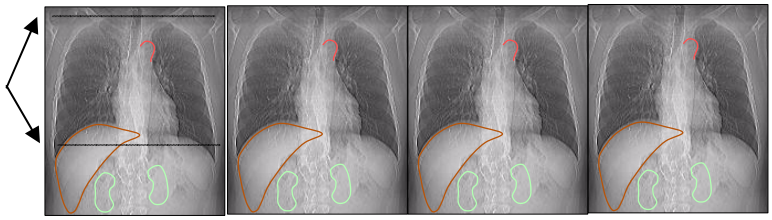
3. Sequences (1-4)

   Data should be completed for each scanning sequence in the particular examination. If more than 4 sequences are used for an entire examination, then additional forms

should be used (any continuation sheets should be clearly marked and linked to the initial sheet).

4. Anatomical range diagrams

Indicate clearly, using straight lines on the images, the start and stop positions for each sequence of images.



5. Anatomical range

Describe the range of the scan sequence (e.g. lung base to apices).

6. Standard protocol sequence or *ad-hoc* sequence

Indicate whether the sequence is routinely performed for every patient or only in response to findings in a previous sequence. When completing the routine protocol section of the survey, include any common (i.e. performed for at least a quarter of patients) additional sequences (e.g. following a routine head scan, an additional *ad-hoc* sequence may be performed using a contrast agent, if a tumour is suspected from the previous images).

7. IV contrast

Indicate if an IV contrast agent is used for the sequence. Indicate which phase of contrast enhancement is being imaged (e.g. arterial or venous phase).

8. Nominal beam collimation

Indicate the x-ray beam collimation as selected on the console. For single slice scanners, this will usually be the same as the imaged slice width. For multi-slice scanners, indicate the number of slices per rotation, as well as the acquired slice width (e.g. 4 x 1mm).

N.B Ignore any known variation between the displayed value and the actual value used (e.g. post-patient collimation).

9. Scanned field of view

Indicate the scanned or acquisition field of view (e.g. 50 cm or "Body").

N.B This is not the same parameter as the reconstructed field of view, which can be smaller.

10. Tube voltage

Indicate the tube voltage used for each sequence scanned.

11. Tube rotation time

Indicate the rotation time selected on the scanner console (include partial rotation times).

12. Tube current

Indicate the tube current (set mA) used for the sequence. For the protocol survey, indicate the set mA for a standard patient. Ignore any dose saving (mA modulation) options that the scanner may use.

13. mAs

Indicate the displayed mAs used for the sequence. Since different scanners indicate mAs in different ways, please tick one box to show which value your scanner displays: mAs, mAs/slice or effective mAs. For the protocol survey, indicate the mAs displayed for a standard patient.

14. Auto dose reduction (mA modulation)

If your scanner has mA modulation, indicate the system used and also the average mA as given by the scanner, if available. On some models, other information (e.g. maximum mA used) may be given. Please indicate the basis for the value you provide.

15. Axial or helical scanning

Axial (or “step and shoot”) mode is available on all scanner types. Helical or spiral mode is available on all multi-slice scanners and most single slice units. Indicate the scanning mode used for each sequence.

16. No. Axial slices/ scan length (individual patient survey only)

For axial mode, indicate the number of slices scanned for each sequence. For helical scanning, indicate the range scanned (mm) as indicated by the start and stop positions.

17. Table increment/ pitch

For axial scanning, indicate the table increment (in mm) between slices. For helical scanning, indicate the pitch if known. On some multi-slice models, the pitch may be assigned a name (e.g. HQ or HS mode).

18. Overscan or partial scan (axial scanning only)

State degrees of scan angle if known, otherwise indicate if either mode has been used.

19. Table speed/ travel (helical scanning only)

This value will be used by the survey team, in conjunction with the collimated beam width, to calculated pitch if the latter is not provided.

20. Reconstruction interval (helical scanning only)

Indicate the spacing of the reconstructed slices.

21. Imaged slice thickness.

Indicate the thickness of the slices reconstructed from the data. For some scanners, the images may be reconstructed and then fused. The fused thickness should be recorded.

22. $CTDI_w$, $CTDI_{vol}$, DLP (DLP for individual patient survey only)

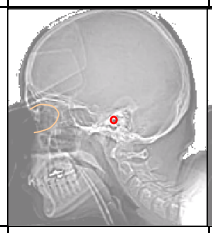
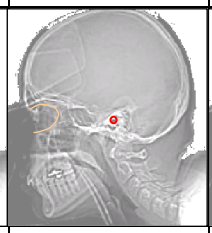
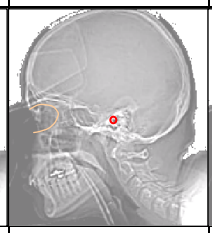
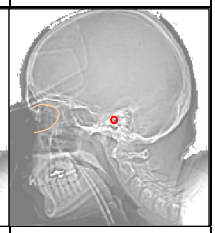
Where $CTDI_w$, $CTDI_{vol}$ or DLP are displayed on the console, the values should be included on the form. If these quantities are not displayed on the console, this part of the form may be left blank and the survey team will derive the data.

23. Comments

Please add, at the bottom of each form, any relevant comments in support of the data provided.

Examination: **Routine head [Adult]**
Indication: **Acute stroke**

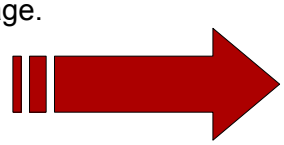
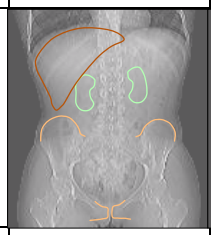
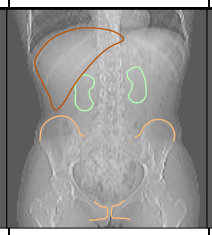
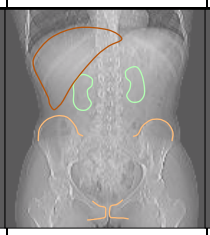
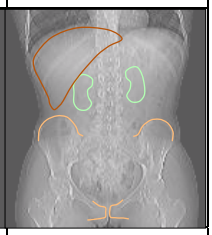
Manufacturer:	**Model:**	**Hospital:**

Routine Protocol Survey		Provide data for each axial or helical scan sequence of the examination.			
		Sequence 1	**Sequence 2**	**Sequence 3**	**Sequence 4**
Indicate the usual start and end positions with lines on each image. 					
Describe anatomical range scanned					
Standard sequence (*routine*) or additional in response to initial findings (*ad-hoc*)		θ Routine θ Ad-hoc	θ Routine θ Ad-hoc	θ Routine θ Ad-hoc	θ Routine θ Ad-hoc
IV contrast used? If YES, indicate name of phase		θ Y θ N	θ Y θ N	θ Y θ N	θ Y θ N
Nominal beam collimation (mm) (combination for multi-slice, e.g. 4 × 1mm)					
Scan field of view (mm or e.g. Head/ Body)					
Tube voltage (kV)					
Tube rotation time (s)					
Tube current (mA)					
Displayed mAs (mAs θ mAs/slice θ effective mAs θ)					
Auto dose reduction used? Y/N Give name of system					
Axial Scanning	**Helical Scanning**	θ Axial θ Helical	θ Axial θ Helical	θ Axial θ Helical	θ Axial θ Helical
Table incr. (mm)	Pitch				
Overscan or partial scan angle (+° or -°)	Table speed/travel (mm per rotation)				
	Reconstr. int. (mm)				
Imaged slice thickness (mm)					
$CTDI_w$ (as indicated on console) mGy					

Comments:

Examination: Abdomen [Adult]
Indication: Liver metastases

Manufacturer:	**Model:**	**Hospital:**

Routine Protocol Survey		Provide data for each axial or helical scan sequence of the examination.			
		Sequence 1	**Sequence 2**	**Sequence 3**	**Sequence 4**
Indicate the usual start and end positions with lines on each image. 					
Describe anatomical range scanned					
Standard sequence (*routine*) or additional in response to initial findings (*ad-hoc*)		θ Routine θ Ad-hoc	θ Routine θ Ad-hoc	θ Routine θ Ad-hoc	θ Routine θ Ad-hoc
IV contrast used? If YES, indicate name of phase		θ Y θ N	θ Y θ N	θ Y θ N	θ Y θ N
Nominal beam collimation (mm) (combination for multi-slice, e.g. 4 × 1mm)					
Scan field of view (mm or e.g. Head/ Body)					
Tube voltage (kV)					
Tube rotation time (s)					
Tube current (mA)					
Displayed mAs (mAs θ mAs/slice θ effective mAs θ)					
Auto dose reduction used? Y/N Give name of system					
Axial Scanning	**Helical Scanning**	θ Axial θ Helical	θ Axial θ Helical	θ Axial θ Helical	θ Axial θ Helical
Table incr. (mm)	Pitch				
Overscan or partial scan angle (+° or -°)	Table speed/travel (mm per rotation)				
	Reconstr. int. (mm)				
Imaged slice thickness (mm)					
$CTDI_w$ (as indicated on console) mGy					

Comments:

12 APPENDIX 3

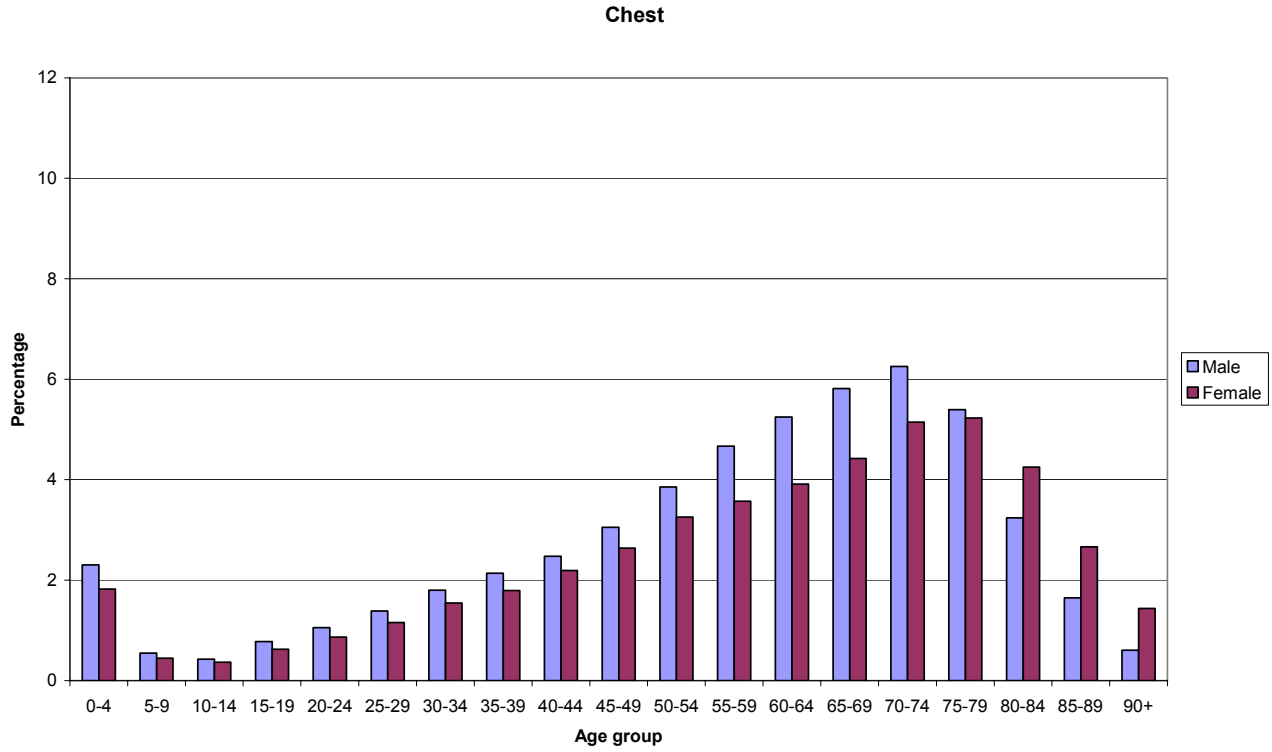
Typical European age/sex data for x-ray patients

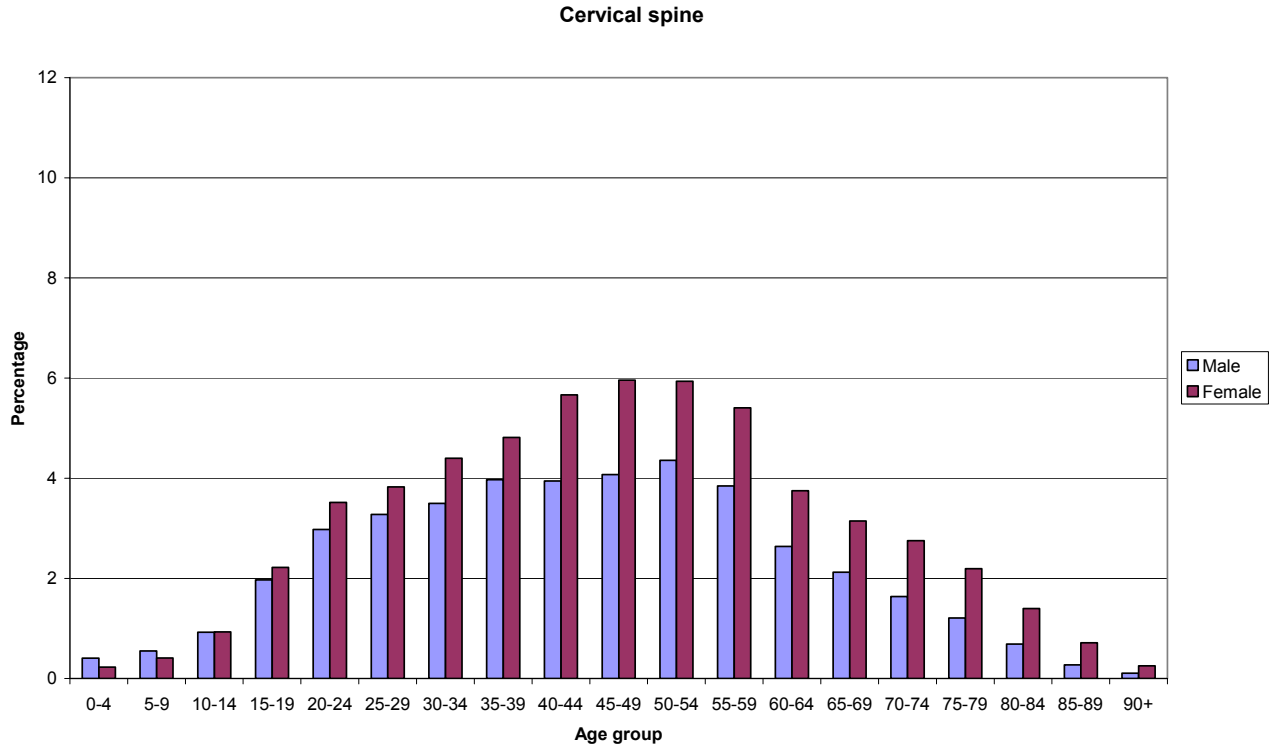
The Figures below show the typical age/sex distributions for the 'Top 20 Exams' that were found to be among the major contributors to the collective effective dose in the ten DOSE DATAMED countries and for 'all angiographic', 'all CT' and 'all interventional' procedures. The distributions are based on the average data from five of the DOSE DATAMED countries, weighted according to the sample size in each country (as shown in section 5, Table 18). The data are divided into five-year age bands and the percentage that is indicated for each band and each gender is taken with respect to the total number of examinations carried out on both male and female patients. The relative height of the male and female bars in each age band therefore indicates the ratio of the numbers of examinations performed on male and female patients. It can be seen, for example, that more females than males have lumbar spine, pelvis and barium enema examinations, particularly in the higher age bands, whereas more males than females undergo IVU, cardiac angiography, and CT chest examinations.

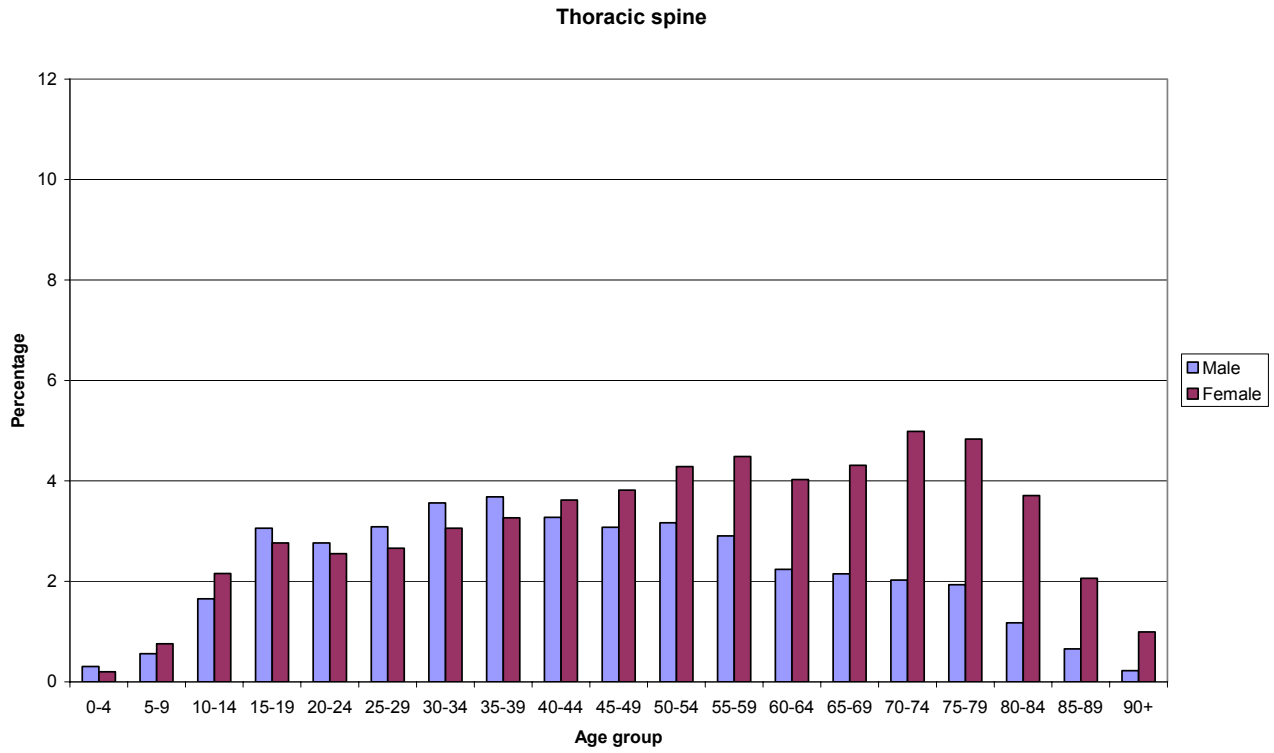
These percentages are also presented numerically in Table A3.1, which appears after the Figures, along with the total percentage for each gender.

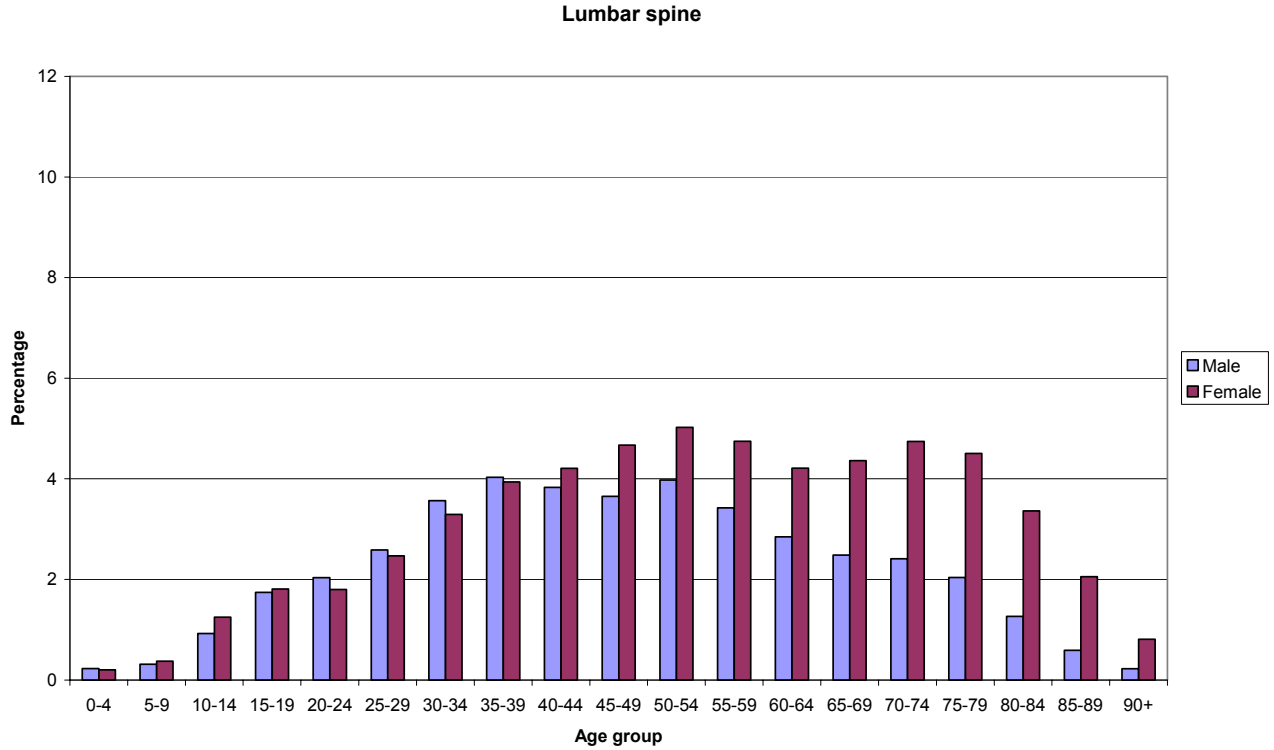
It is suggested that these typical European figures can provide a useful guide to the age and sex distributions for these important types and categories of examination that can be used by any European country to relate collective doses to collective detriment, in the absence of more reliable national data.

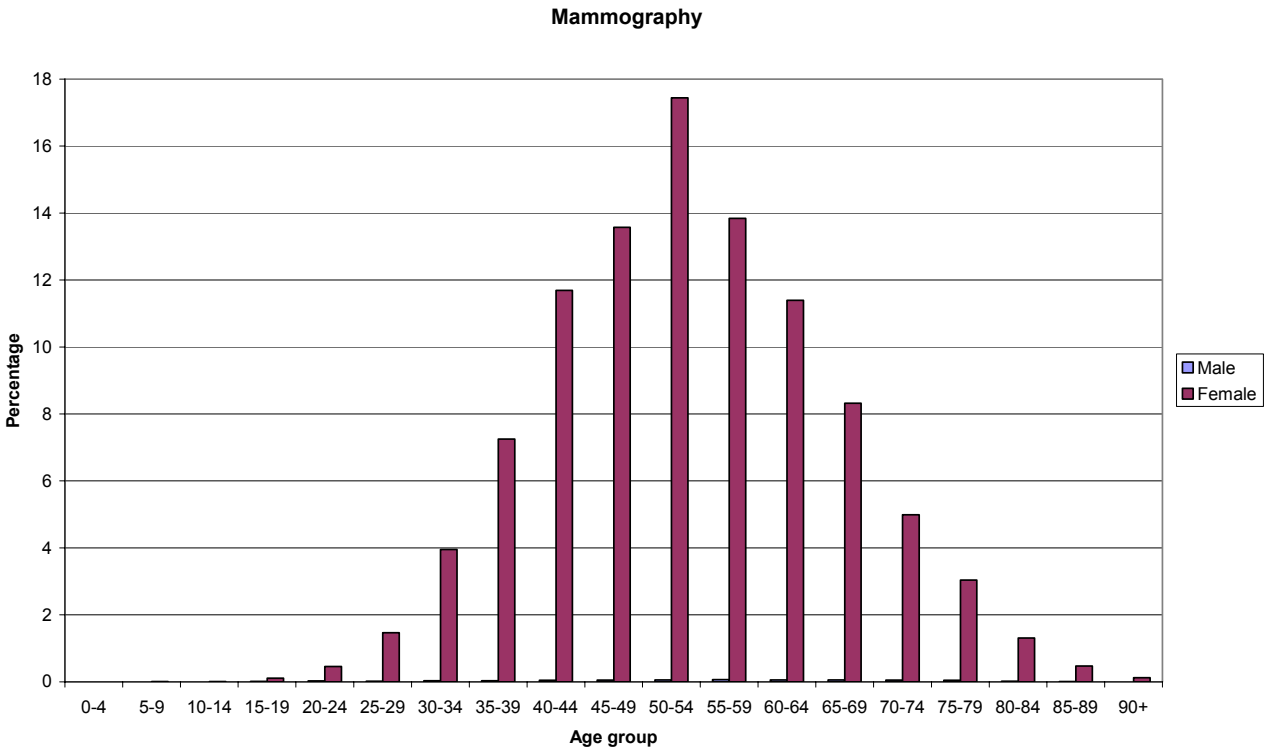
Averaged European age-sex distributions for 20 types of x-ray examination

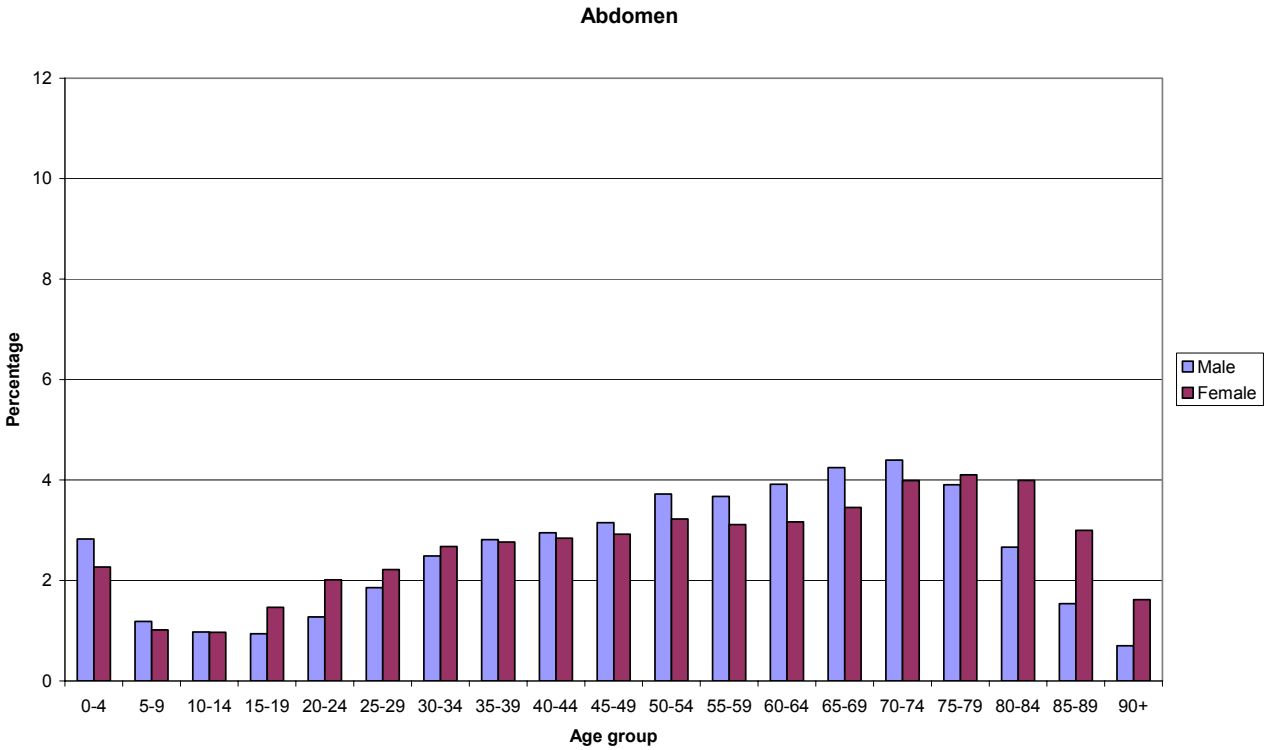




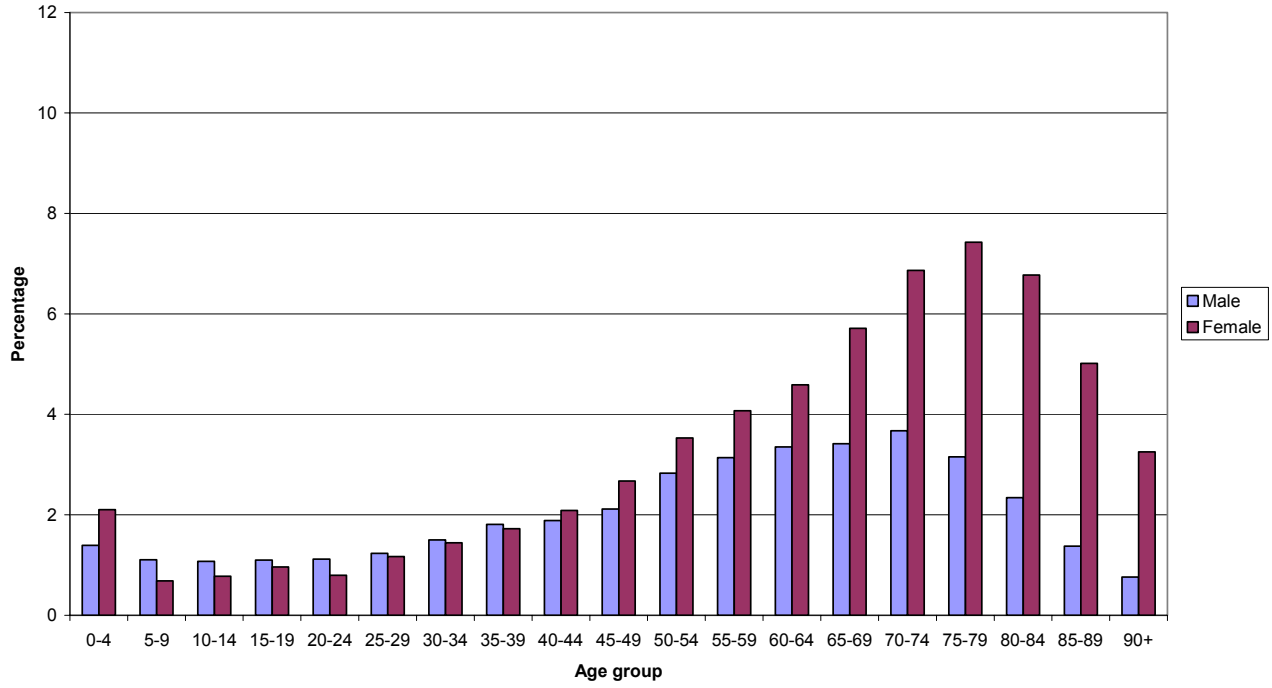

Thoracic spine
12
10
8
6
4
2
0
Percentage
0-4
5-9
10-14
15-19
20-24
25-29
30-34
35-39
40-44
45-49
50-54
55-59
60-64
65-69
70-74
75-79
80-84
85-89
90+
Age group
Male
Female


Lumbar spine
12
10
8
6
4
2
0
Percentage
0-4
5-9
10-14
15-19
20-24
25-29
30-34
35-39
40-44
45-49
50-54
55-59
60-64
65-69
70-74
75-79
80-84
85-89
90+
Age group
Male
Female

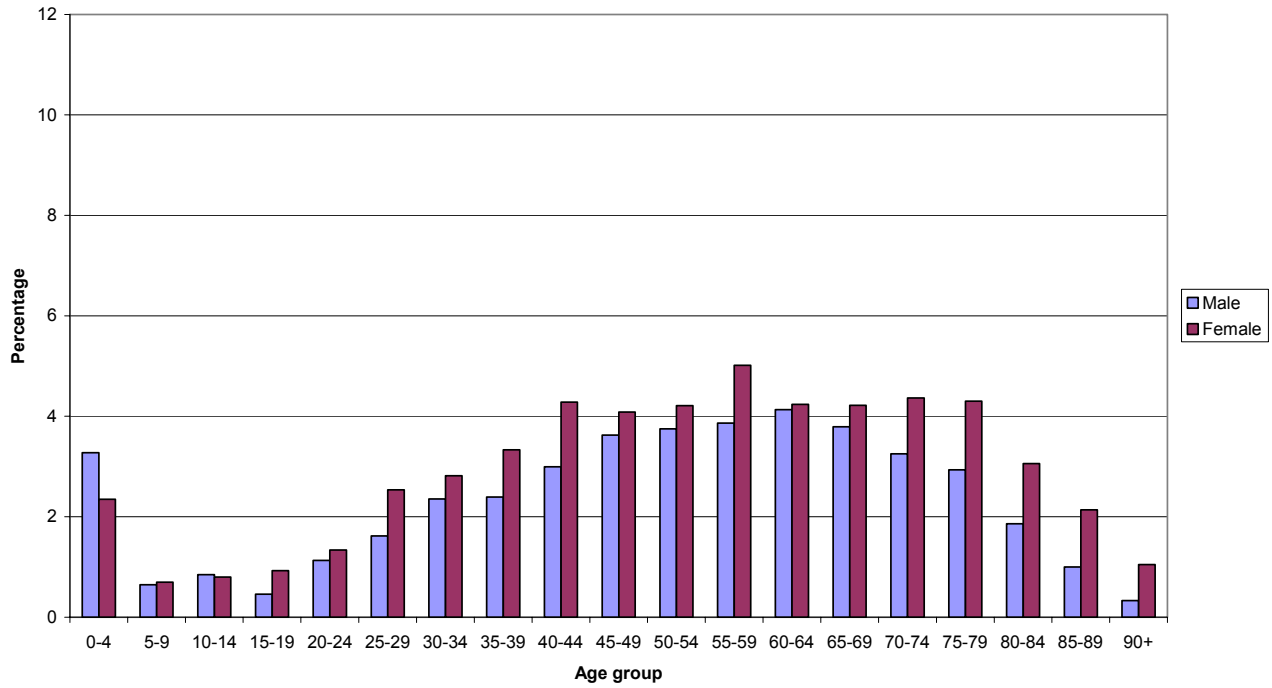

Mammography
Percentage
18
16
14
12
10
8
6
4
2
0
0-4
5-9
10-14
15-19
20-24
25-29
30-34
35-39
40-44
45-49
50-54
55-59
60-64
65-69
70-74
75-79
80-84
85-89
90+
Age group
Male
Female


Abdomen
Percentage
12
10
8
6
4
2
0
0-4
5-9
10-14
15-19
20-24
25-29
30-34
35-39
40-44
45-49
50-54
55-59
60-64
65-69
70-74
75-79
80-84
85-89
90+
Age group
Male
Female

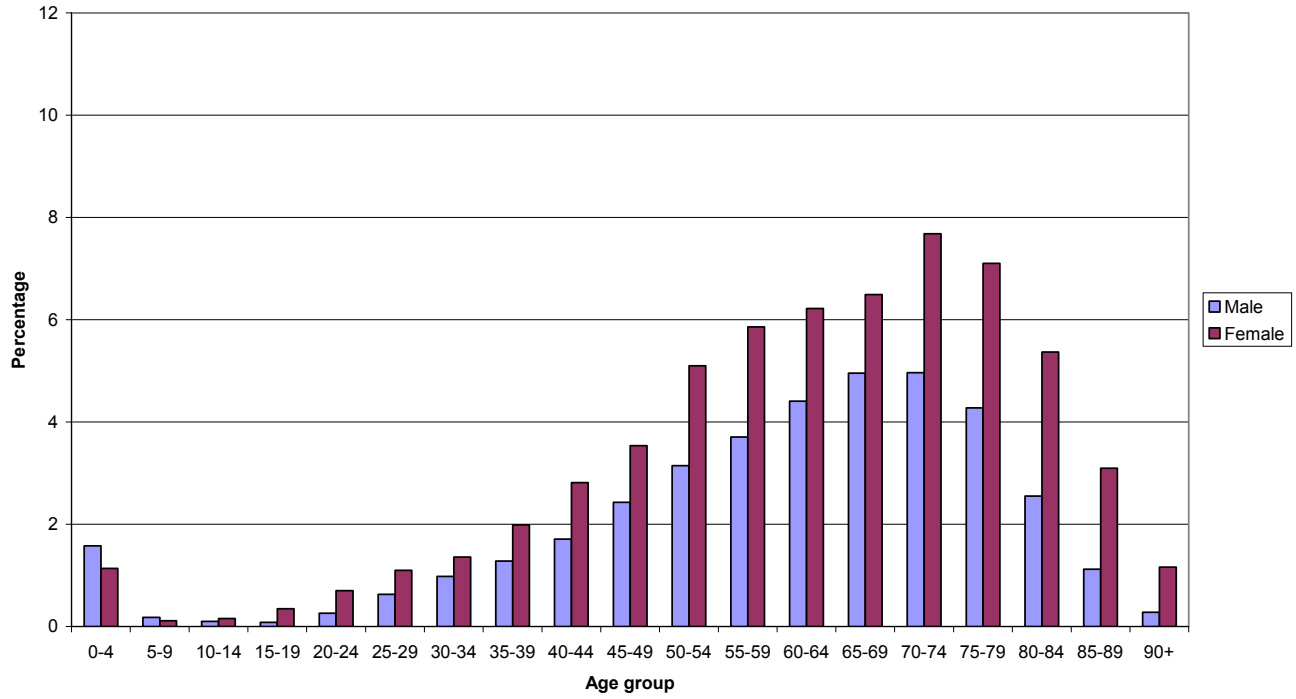
Pelvis



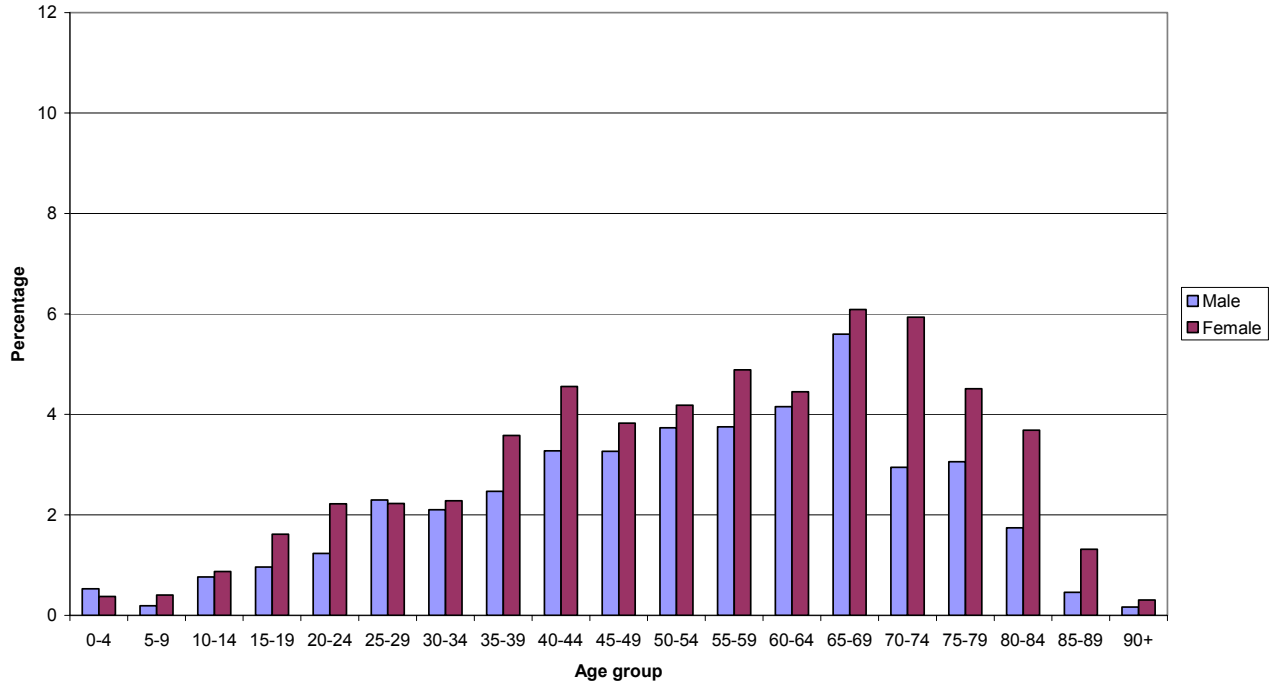
Barium meal



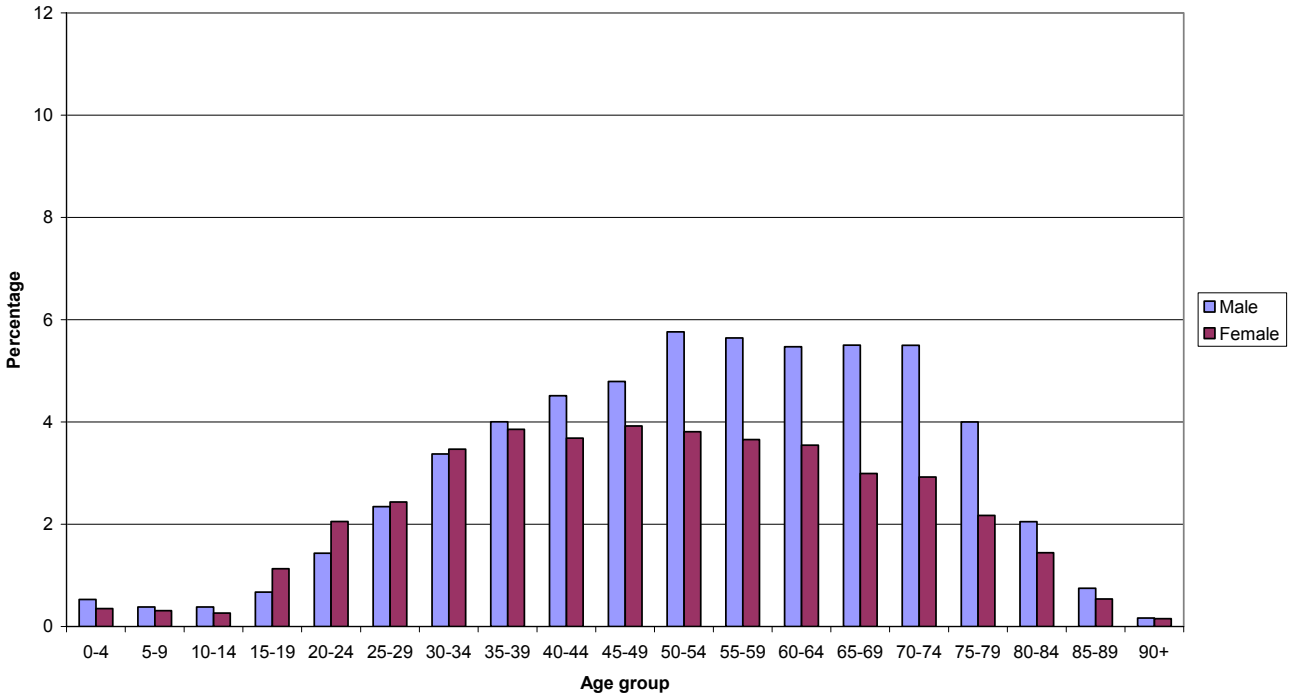
Barium enema



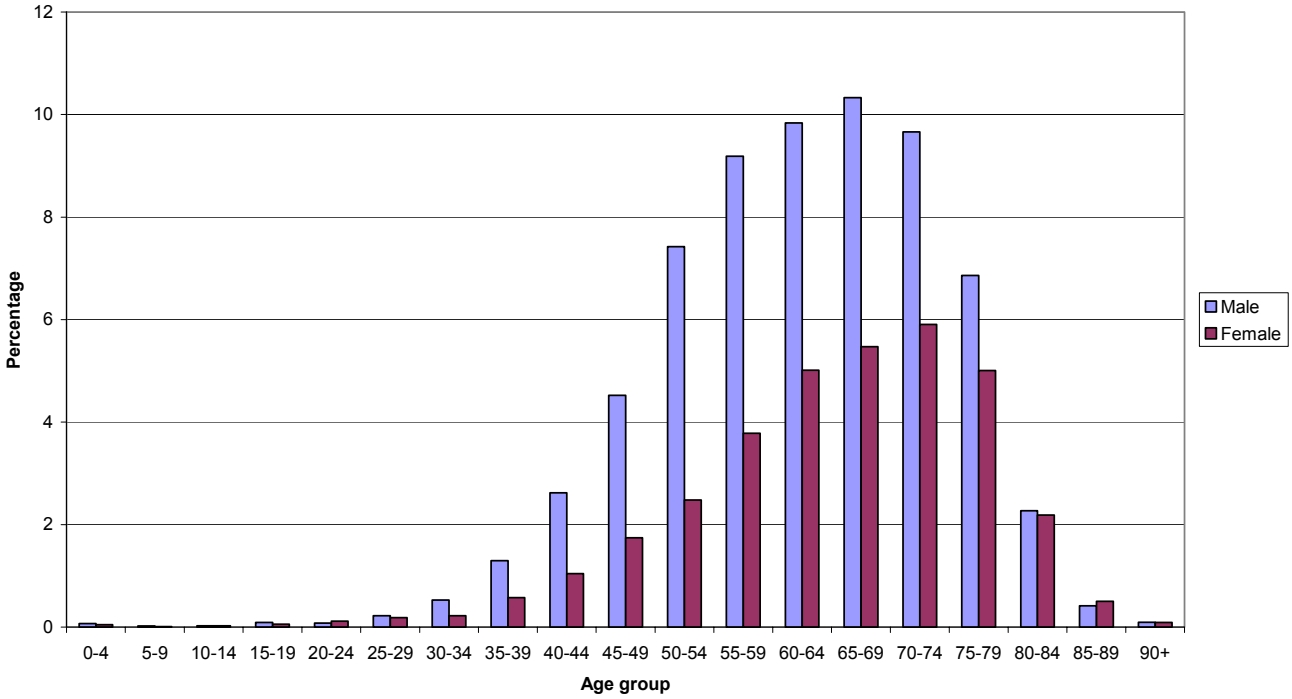
Barium followthrough

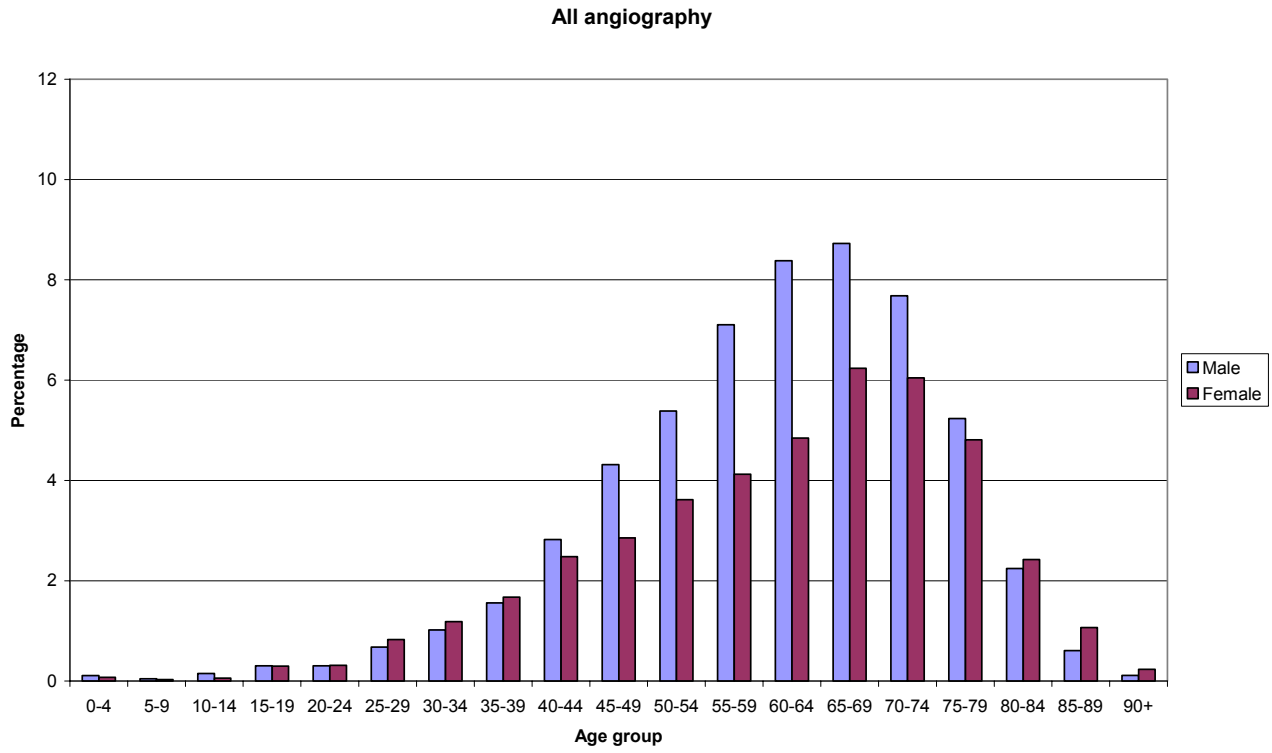


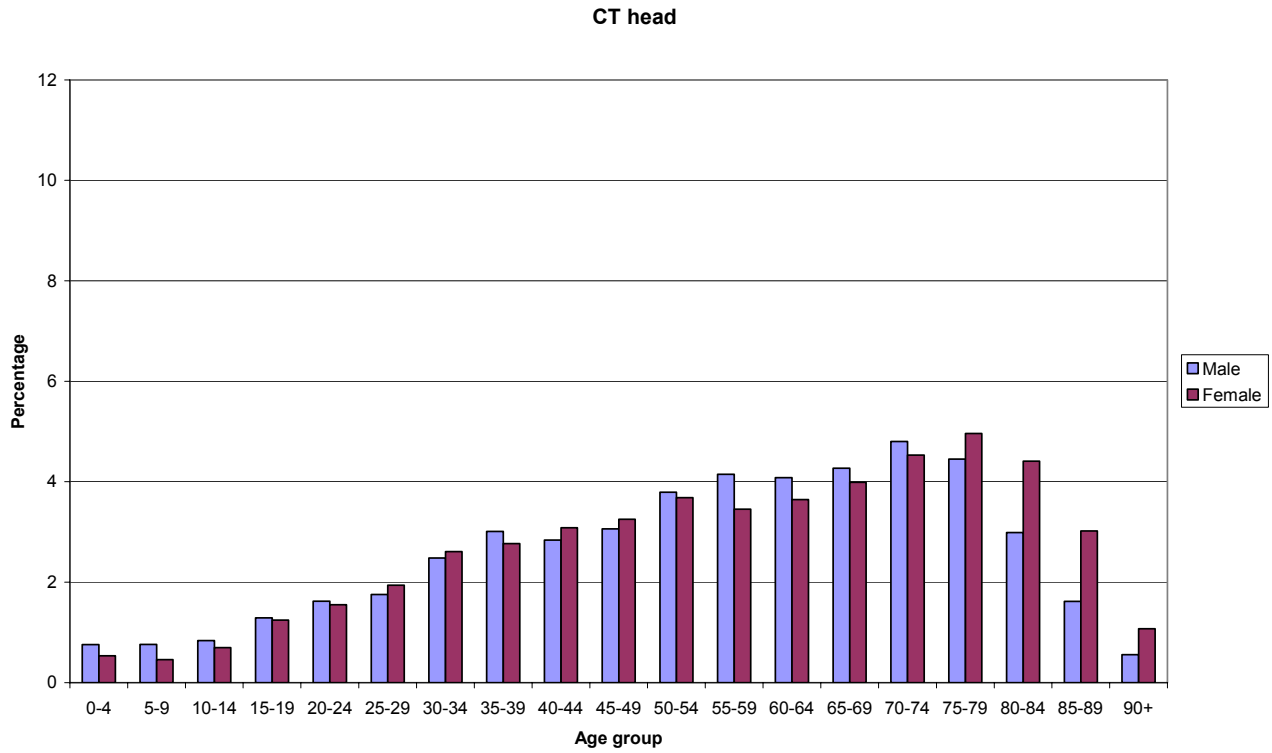
IVU

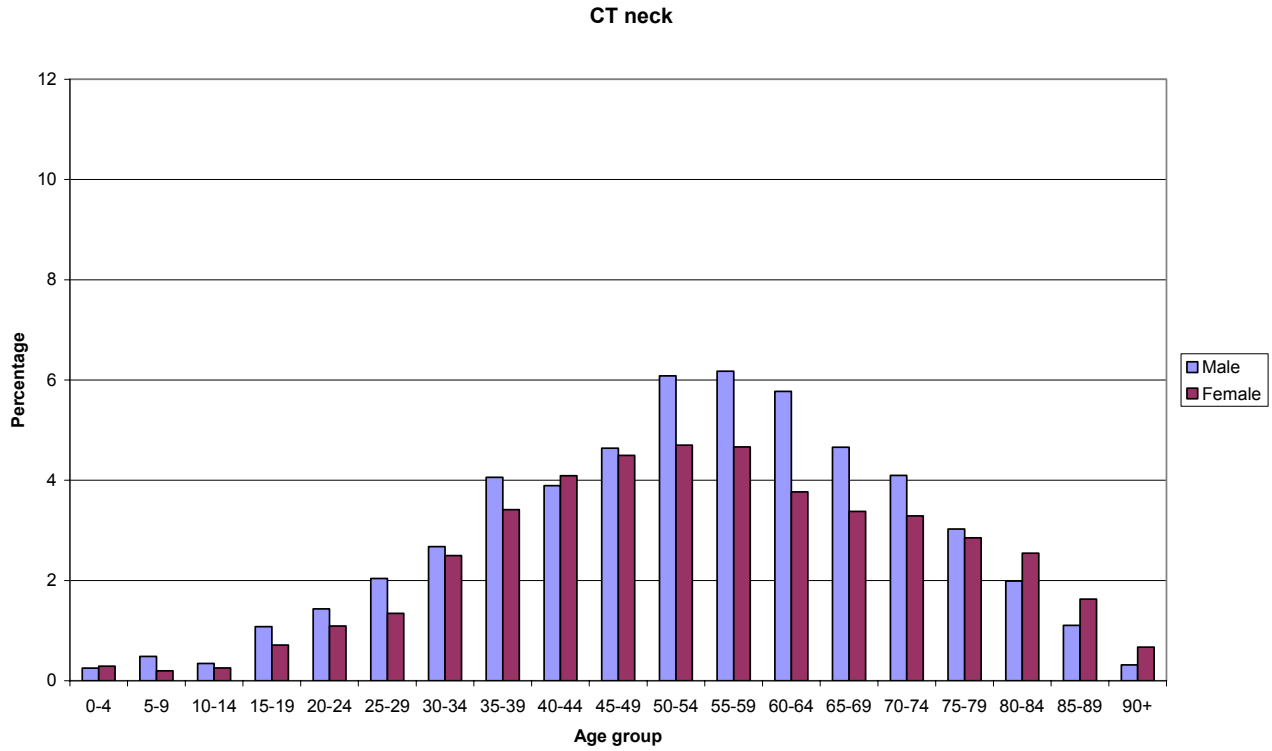


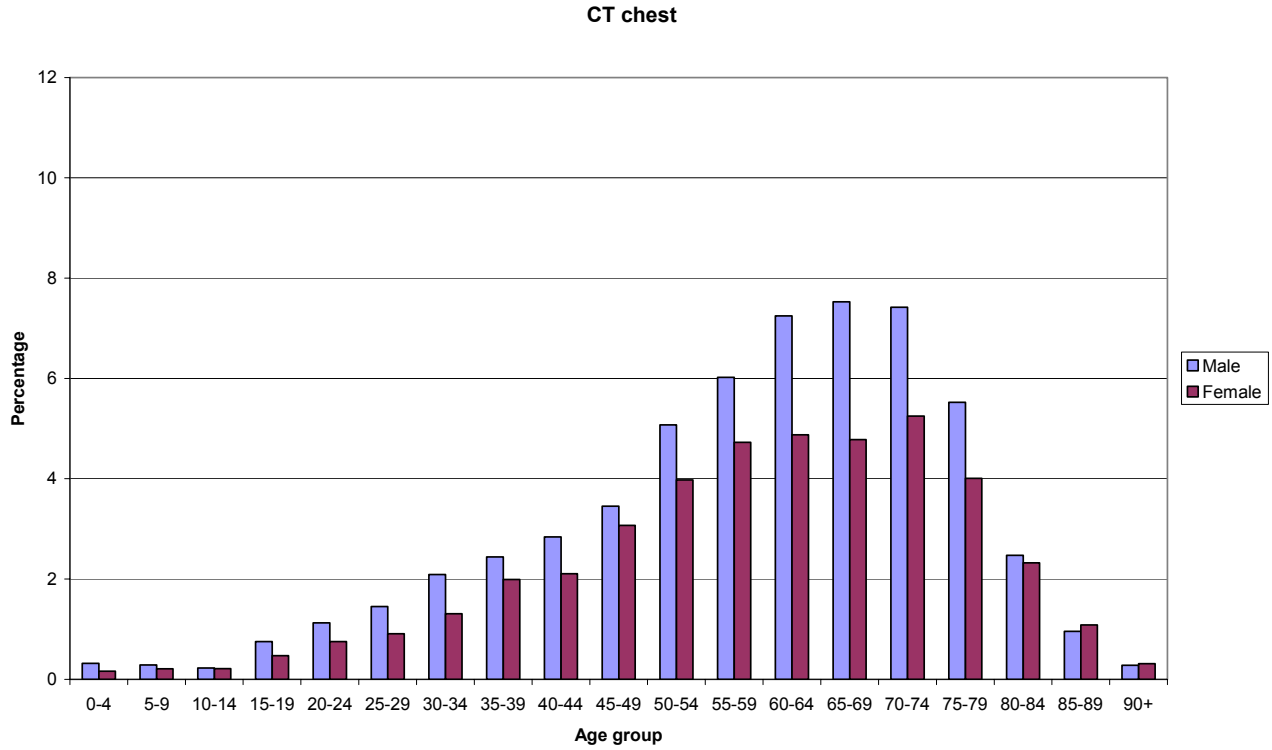
Cardiac angiography

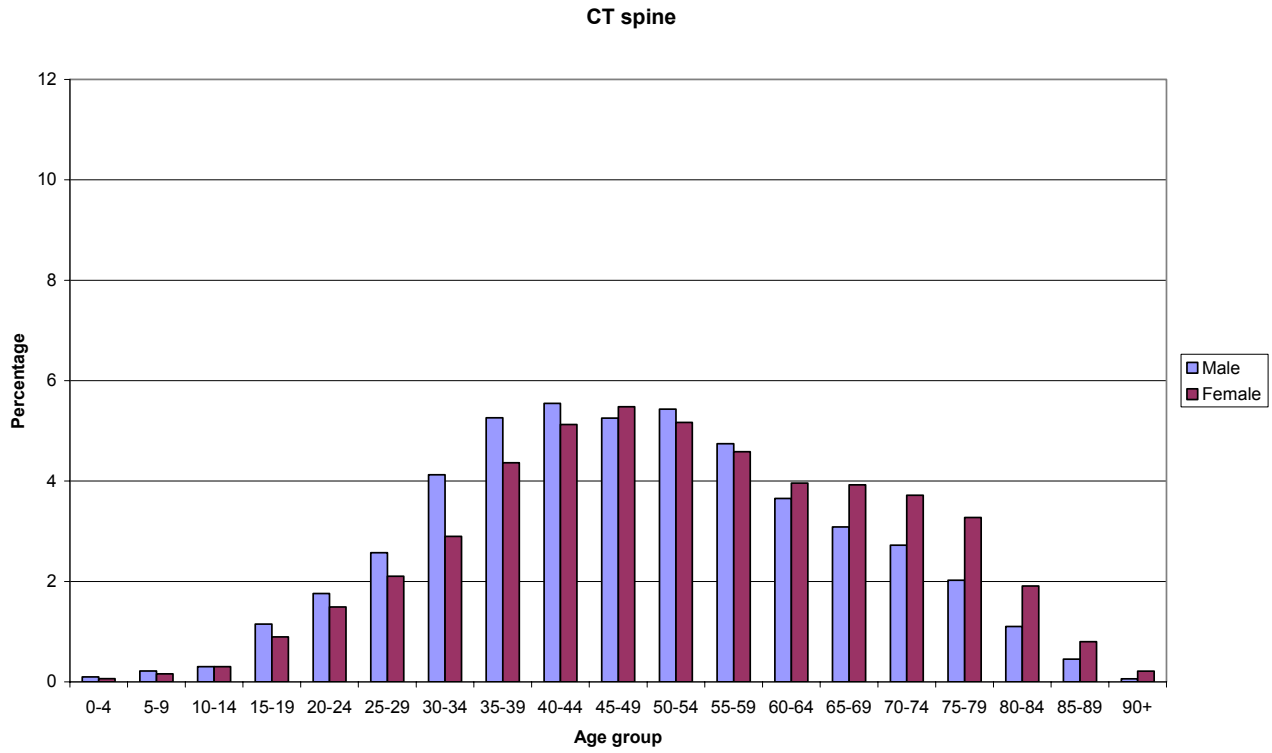


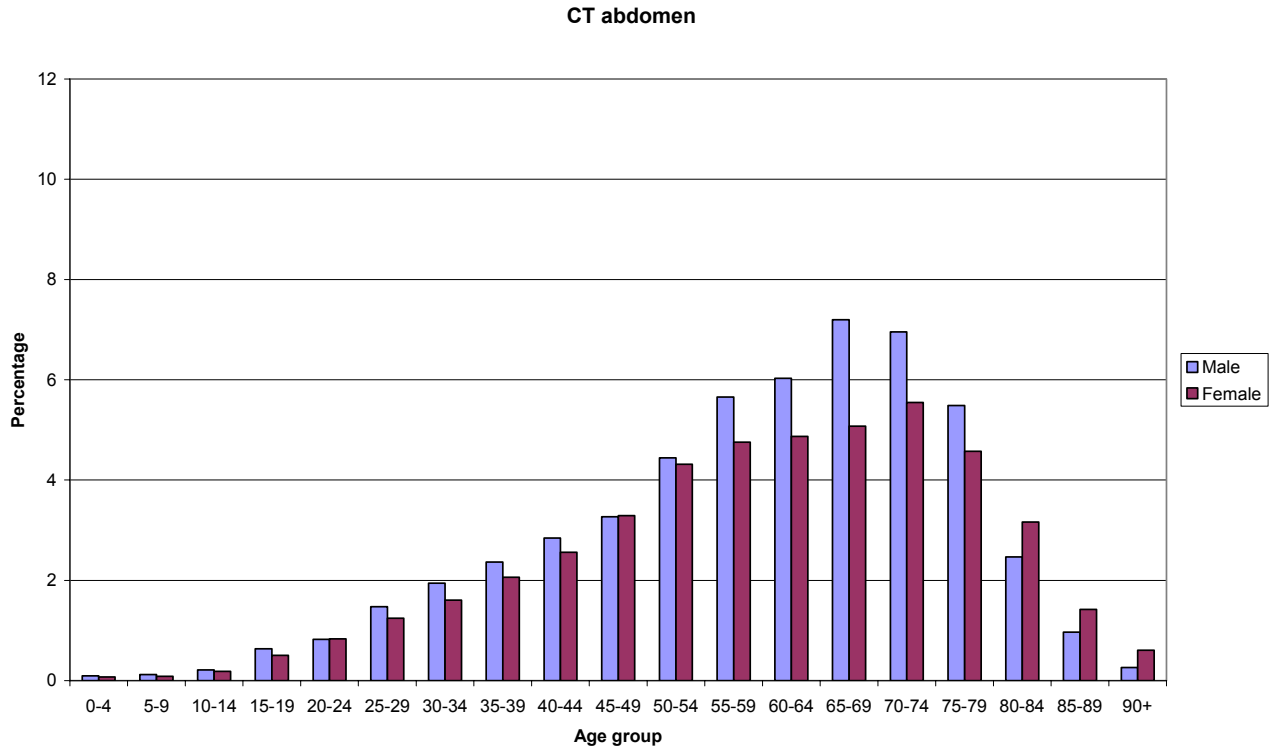

All angiography
Percentage
12
10
8
6
4
2
0
0-4
5-9
10-14
15-19
20-24
25-29
30-34
35-39
40-44
45-49
50-54
55-59
60-64
65-69
70-74
75-79
80-84
85-89
90+
Age group
Male
Female

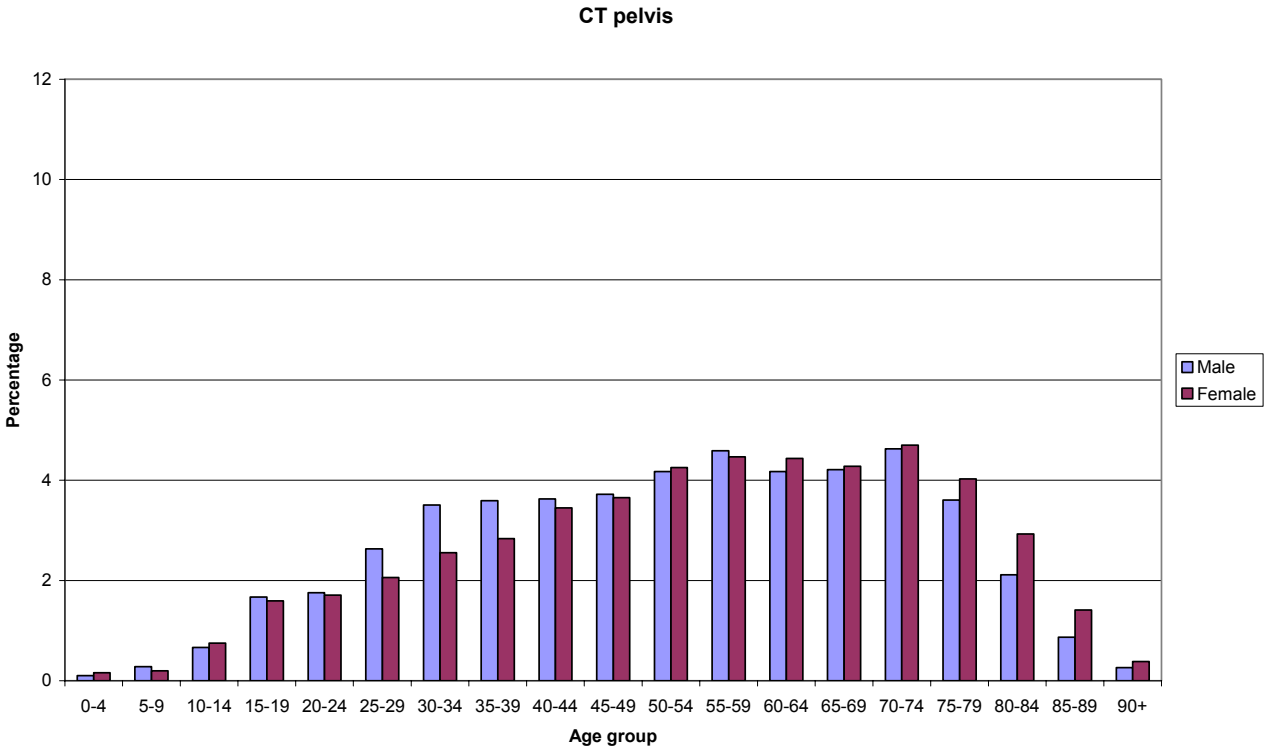

CT head
Percentage
12
10
8
6
4
2
0
0-4
5-9
10-14
15-19
20-24
25-29
30-34
35-39
40-44
45-49
50-54
55-59
60-64
65-69
70-74
75-79
80-84
85-89
90+
Age group
Male
Female

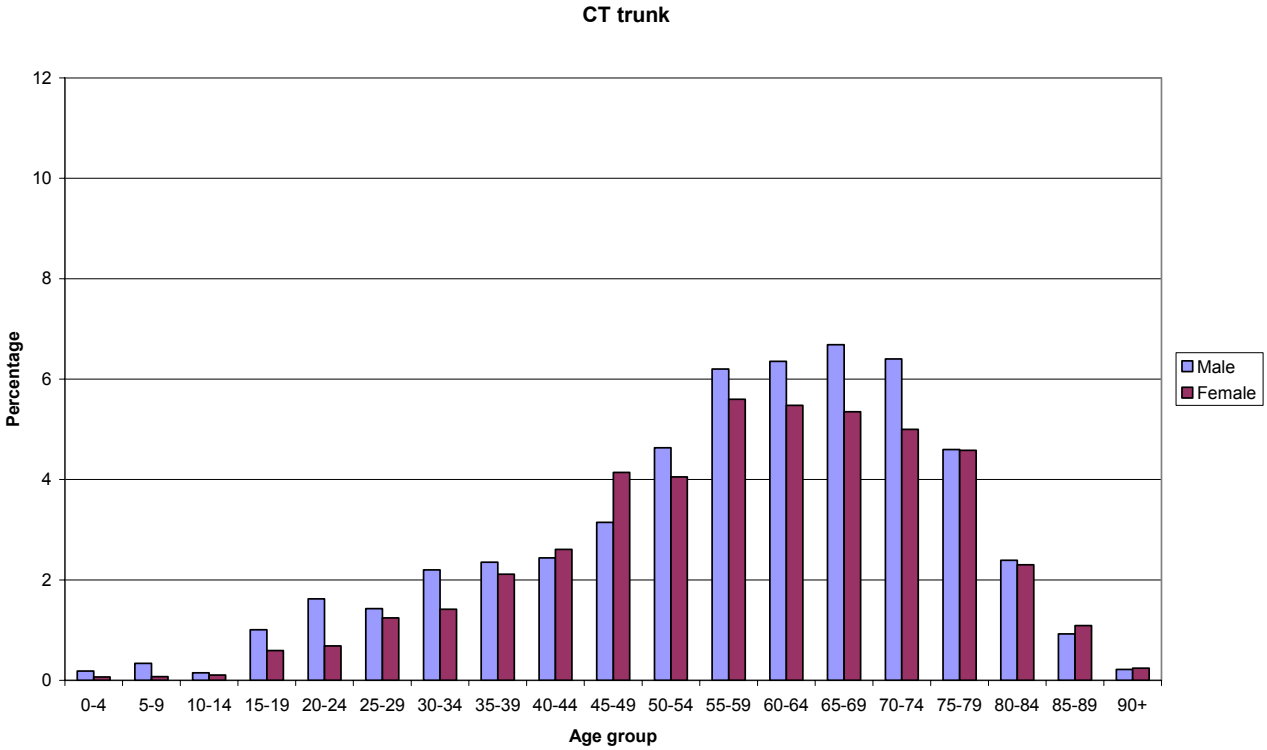

CT neck
12
10
8
6
4
2
0
Percentage
0-4
5-9
10-14
15-19
20-24
25-29
30-34
35-39
40-44
45-49
50-54
55-59
60-64
65-69
70-74
75-79
80-84
85-89
90+
Age group
Male
Female

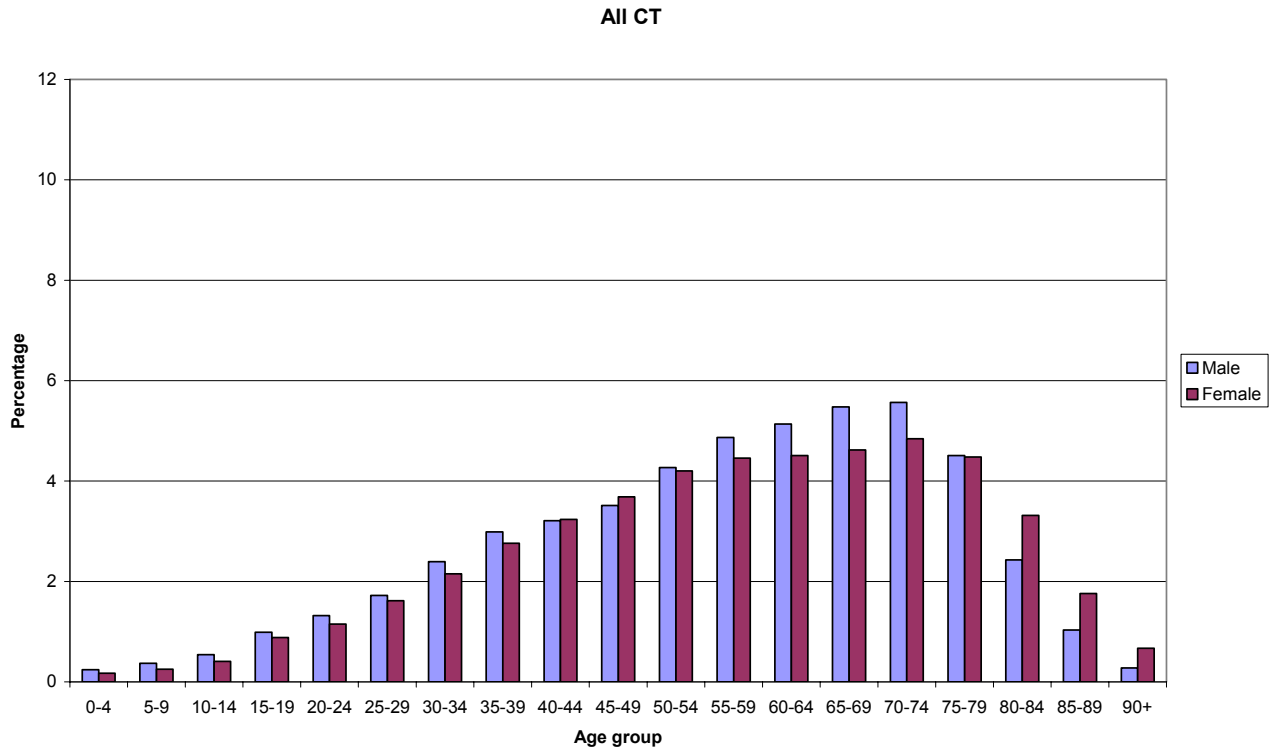

CT chest
12
10
8
6
4
2
0
Percentage
0-4
5-9
10-14
15-19
20-24
25-29
30-34
35-39
40-44
45-49
50-54
55-59
60-64
65-69
70-74
75-79
80-84
85-89
90+
Age group
Male
Female

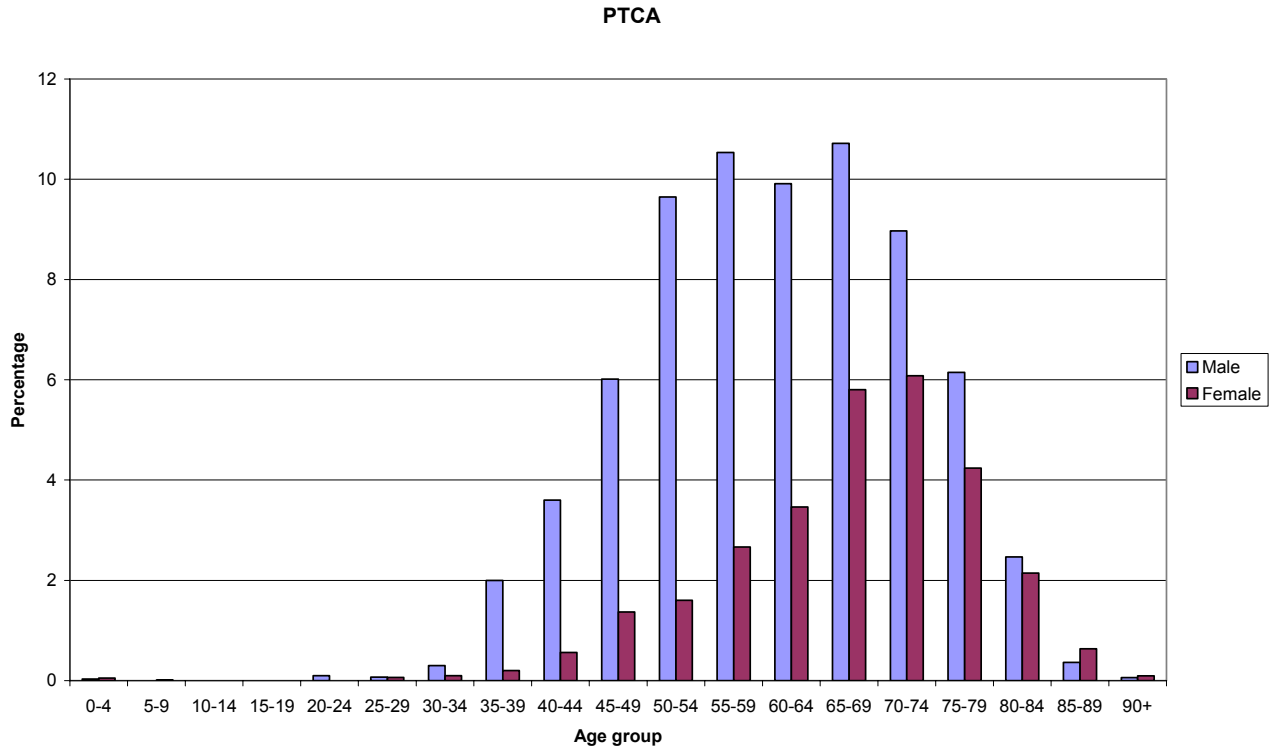

CT spine
Percentage
12
10
8
6
4
2
0
0-4
5-9
10-14
15-19
20-24
25-29
30-34
35-39
40-44
45-49
50-54
55-59
60-64
65-69
70-74
75-79
80-84
85-89
90+
Age group
Male
Female


CT abdomen
Percentage
12
10
8
6
4
2
0
0-4
5-9
10-14
15-19
20-24
25-29
30-34
35-39
40-44
45-49
50-54
55-59
60-64
65-69
70-74
75-79
80-84
85-89
90+
Age group
Male
Female


CT pelvis
12
10
8
6
4
2
0
Percentage
0-4
5-9
10-14
15-19
20-24
25-29
30-34
35-39
40-44
45-49
50-54
55-59
60-64
65-69
70-74
75-79
80-84
85-89
90+
Age group
Male
Female


CT trunk
12
10
8
6
4
2
0
Percentage
0-4
5-9
10-14
15-19
20-24
25-29
30-34
35-39
40-44
45-49
50-54
55-59
60-64
65-69
70-74
75-79
80-84
85-89
90+
Age group
Male
Female


All CT
Percentage
12
10
8
6
4
2
0
0-4
5-9
10-14
15-19
20-24
25-29
30-34
35-39
40-44
45-49
50-54
55-59
60-64
65-69
70-74
75-79
80-84
85-89
90+
Age group
Male
Female


PTCA
Percentage
12
10
8
6
4
2
0
0-4
5-9
10-14
15-19
20-24
25-29
30-34
35-39
40-44
45-49
50-54
55-59
60-64
65-69
70-74
75-79
80-84
85-89
90+
Age group
Male
Female

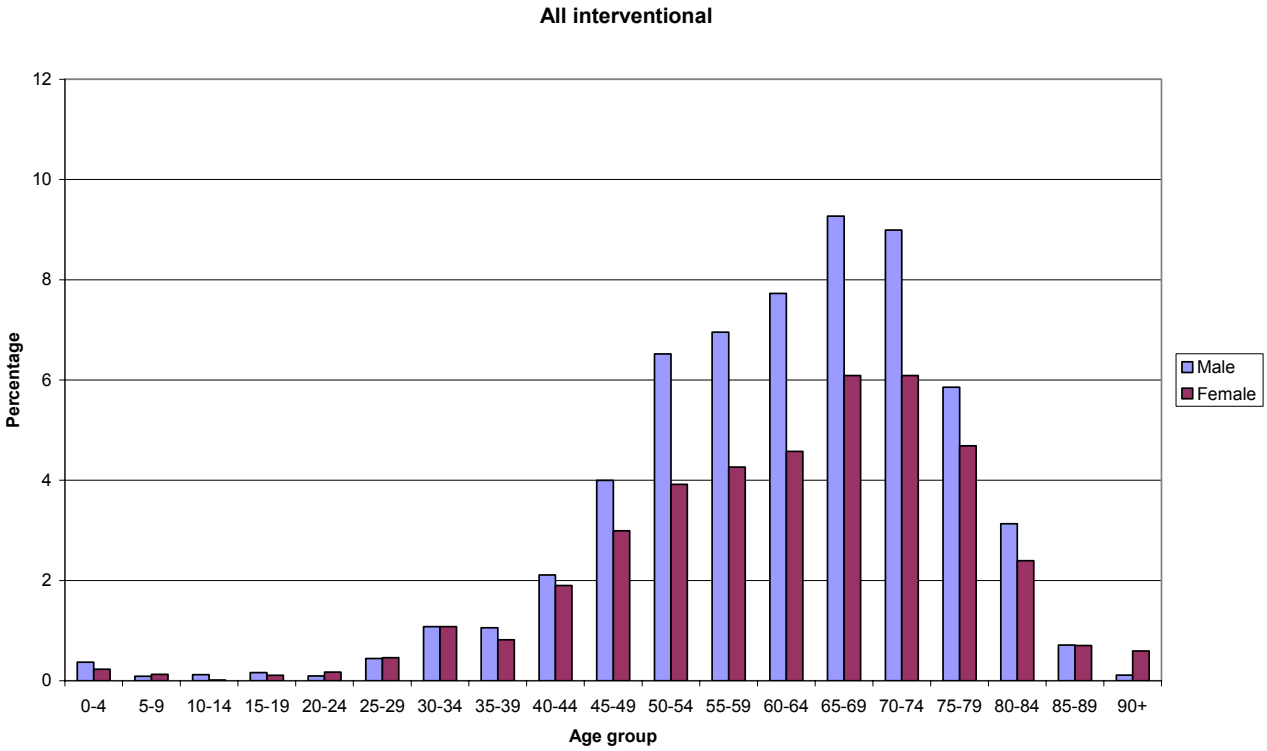

All interventional
12
10
8
6
4
2
0
Percentage
0-4
5-9
10-14
15-19
20-24
25-29
30-34
35-39
40-44
45-49
50-54
55-59
60-64
65-69
70-74
75-79
80-84
85-89
90+
Age group
Male
Female

TABLE A3.1: Averaged European age/sex distributions (percentage) for radiographic examinations

Age band	Chest		Cervical spine		Thoracic spine		Lumbar spine		Mammo		Abdomen		Pelvis	
	F	M	F	M	F	M	F	M	F	M	F	M	F	M
0-4	1.82	2.30	0.23	0.41	0.20	0.30	0.21	0.23	0.00	0.00	2.27	2.82	2.10	1.39
5-9	0.44	0.55	0.41	0.55	0.76	0.56	0.38	0.32	0.01	0.00	1.02	1.18	0.68	1.11
10-14	0.37	0.42	0.93	0.93	2.16	1.65	1.25	0.92	0.00	0.00	0.97	0.97	0.78	1.07
15-19	0.62	0.78	2.22	1.97	2.76	3.06	1.81	1.74	0.11	0.01	1.46	0.94	0.96	1.10
20-24	0.87	1.05	3.51	2.98	2.55	2.77	1.80	2.03	0.46	0.02	2.01	1.27	0.79	1.12
25-29	1.15	1.38	3.82	3.28	2.66	3.09	2.47	2.58	1.47	0.02	2.21	1.85	1.17	1.23
30-34	1.55	1.80	4.40	3.50	3.06	3.56	3.29	3.57	3.95	0.03	2.68	2.49	1.45	1.50
35-39	1.79	2.14	4.82	3.97	3.27	3.68	3.94	4.03	7.25	0.03	2.76	2.81	1.72	1.81
40-44	2.19	2.47	5.66	3.94	3.62	3.27	4.21	3.83	11.69	0.04	2.84	2.95	2.08	1.89
45-49	2.64	3.05	5.96	4.07	3.82	3.08	4.67	3.65	13.57	0.05	2.92	3.15	2.67	2.11
50-54	3.26	3.85	5.94	4.36	4.29	3.17	5.02	3.97	17.44	0.06	3.22	3.72	3.53	2.83
55-59	3.57	4.67	5.41	3.85	4.49	2.91	4.75	3.42	13.84	0.06	3.11	3.67	4.07	3.14
60-64	3.91	5.25	3.75	2.64	4.02	2.24	4.21	2.85	11.40	0.06	3.17	3.92	4.59	3.35
65-69	4.42	5.81	3.15	2.12	4.31	2.15	4.36	2.48	8.32	0.06	3.45	4.25	5.71	3.41
70-74	5.15	6.25	2.75	1.64	4.98	2.02	4.74	2.41	4.99	0.05	3.99	4.40	6.87	3.67
75-79	5.23	5.39	2.19	1.21	4.83	1.93	4.50	2.04	3.04	0.04	4.10	3.91	7.43	3.16
80-84	4.25	3.24	1.40	0.69	3.71	1.18	3.36	1.26	1.30	0.02	3.99	2.66	6.77	2.34
85-89	2.66	1.65	0.71	0.27	2.06	0.65	2.06	0.59	0.47	0.01	3.00	1.54	5.01	1.37
90+	1.43	0.60	0.25	0.11	0.99	0.22	0.81	0.22	0.12	0.00	1.62	0.70	3.25	0.76
Total	47.3	52.7	57.5	42.5	58.5	41.5	57.8	42.2	99.4	0.57	50.8	49.2	61.6	38.4

TABLE A3.1 (cont): Averaged European age/sex distributions (percentage) for fluoroscopy & interventional procedures

Age band	Barium meal		Barium enema		Barium follow		IVU		Cardiac Angio		All Angio		PTCA		All Intervent	
	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
0-4	2.35	3.28	1.14	1.58	0.37	0.53	0.35	0.53	0.05	0.07	0.08	0.11	0.05	0.03	0.23	0.37
5-9	0.69	0.65	0.12	0.18	0.40	0.19	0.31	0.38	0.01	0.02	0.03	0.04	0.01	0.00	0.13	0.09
10-14	0.80	0.84	0.16	0.10	0.87	0.76	0.26	0.38	0.03	0.02	0.06	0.15	0.00	0.00	0.01	0.12
15-19	0.93	0.46	0.35	0.08	1.61	0.96	1.13	0.67	0.05	0.09	0.30	0.31	0.00	0.00	0.11	0.16
20-24	1.34	1.13	0.70	0.26	2.22	1.23	2.05	1.44	0.11	0.08	0.31	0.31	0.00	0.10	0.17	0.09
25-29	2.54	1.62	1.10	0.63	2.23	2.30	2.44	2.34	0.18	0.22	0.83	0.68	0.06	0.07	0.46	0.44
30-34	2.81	2.35	1.36	0.98	2.28	2.10	3.47	3.38	0.22	0.53	1.18	1.02	0.10	0.30	1.08	1.08
35-39	3.33	2.39	1.99	1.28	3.58	2.47	3.86	4.00	0.58	1.29	1.67	1.56	0.20	2.00	0.82	1.06
40-44	4.28	3.00	2.82	1.71	4.56	3.27	3.69	4.51	1.04	2.62	2.48	2.82	0.56	3.60	1.90	2.11
45-49	4.08	3.63	3.54	2.43	3.83	3.27	3.92	4.79	1.74	4.52	2.85	4.32	1.37	6.01	2.99	4.00
50-54	4.21	3.75	5.10	3.14	4.18	3.73	3.81	5.76	2.48	7.42	3.62	5.38	1.60	9.65	3.91	6.52
55-59	5.01	3.86	5.86	3.71	4.89	3.75	3.66	5.64	3.78	9.19	4.12	7.11	2.67	10.53	4.26	6.95
60-64	4.24	4.13	6.22	4.41	4.45	4.15	3.55	5.47	5.01	9.83	4.84	8.38	3.47	9.91	4.58	7.72
65-69	4.21	3.79	6.49	4.96	6.09	5.60	2.99	5.50	5.47	10.33	6.24	8.73	5.81	10.72	6.09	9.27
70-74	4.37	3.25	7.68	4.96	5.94	2.95	2.93	5.50	5.90	9.66	6.05	7.68	6.08	8.97	6.09	8.99
75-79	4.30	2.93	7.10	4.28	4.51	3.06	2.17	4.00	5.01	6.86	4.81	5.23	4.24	6.15	4.69	5.86
80-84	3.06	1.86	5.37	2.55	3.69	1.74	1.44	2.05	2.18	2.27	2.43	2.25	2.14	2.47	2.40	3.13
85-89	2.14	1.00	3.10	1.12	1.31	0.46	0.54	0.75	0.50	0.41	1.06	0.61	0.64	0.36	0.70	0.71
90+	1.05	0.33	1.16	0.28	0.31	0.17	0.15	0.17	0.09	0.09	0.23	0.11	0.10	0.06	0.59	0.11
Total	55.7	44.2	61.4	38.6	57.3	42.7	42.7	57.3	34.5	65.5	43.2	56.8	29.1	70.9	41.2	58.8

TABLE A3.1 (cont): Averaged European age/sex distributions (percentage) for CT examinations

Age band	CT head		CT neck		CT chest		CT spine		CT abdomen		CT pelvis		CT trunk		All CT	
	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
0-4	0.53	0.75	0.29	0.25	0.16	0.32	0.06	0.10	0.07	0.09	0.16	0.10	0.07	0.18	0.17	0.24
5-9	0.46	0.76	0.20	0.49	0.21	0.28	0.16	0.22	0.08	0.12	0.19	0.28	0.07	0.34	0.25	0.37
10-14	0.70	0.84	0.26	0.34	0.21	0.22	0.30	0.30	0.18	0.21	0.75	0.67	0.11	0.15	0.41	0.54
15-19	1.24	1.29	0.71	1.08	0.47	0.75	0.90	1.15	0.50	0.63	1.59	1.67	0.59	1.00	0.88	0.99
20-24	1.55	1.62	1.09	1.43	0.75	1.13	1.49	1.76	0.83	0.82	1.71	1.75	0.69	1.62	1.15	1.32
25-29	1.94	1.75	1.34	2.04	0.91	1.45	2.10	2.57	1.24	1.48	2.06	2.63	1.24	1.43	1.61	1.72
30-34	2.61	2.48	2.50	2.68	1.31	2.09	2.90	4.12	1.61	1.94	2.55	3.51	1.41	2.20	2.15	2.39
35-39	2.77	3.01	3.41	4.06	1.99	2.44	4.36	5.26	2.06	2.37	2.83	3.59	2.12	2.35	2.76	2.99
40-44	3.08	2.84	4.09	3.89	2.11	2.84	5.13	5.55	2.56	2.84	3.45	3.62	2.61	2.44	3.23	3.21
45-49	3.25	3.06	4.50	4.64	3.07	3.45	5.48	5.25	3.29	3.27	3.65	3.72	4.14	3.15	3.68	3.51
50-54	3.68	3.79	4.70	6.08	3.97	5.07	5.17	5.43	4.32	4.45	4.25	4.17	4.05	4.63	4.20	4.27
55-59	3.45	4.15	4.67	6.17	4.73	6.02	4.59	4.74	4.76	5.65	4.47	4.59	5.60	6.20	4.46	4.87
60-64	3.64	4.08	3.77	5.77	4.88	7.25	3.96	3.65	4.87	6.03	4.44	4.17	5.48	6.35	4.51	5.13
65-69	3.99	4.27	3.38	4.66	4.78	7.53	3.93	3.08	5.07	7.20	4.28	4.21	5.35	6.69	4.62	5.48
70-74	4.53	4.80	3.29	4.10	5.25	7.42	3.72	2.72	5.55	6.95	4.70	4.63	5.00	6.40	4.84	5.56
75-79	4.96	4.45	2.85	3.03	4.01	5.52	3.27	2.02	4.57	5.49	4.03	3.61	4.58	4.60	4.48	4.51
80-84	4.41	2.99	2.54	1.99	2.32	2.47	1.91	1.10	3.16	2.47	2.93	2.11	2.30	2.39	3.32	2.43
85-89	3.02	1.62	1.63	1.10	1.08	0.95	0.80	0.45	1.42	0.97	1.41	0.87	1.09	0.93	1.76	1.03
90+	1.07	0.56	0.67	0.31	0.31	0.28	0.21	0.06	0.61	0.26	0.39	0.26	0.24	0.22	0.67	0.28
Total	50.9	49.1	45.9	54.1	42.5	57.5	50.4	49.6	46.8	53.2	49.8	50.2	46.7	53.3	49.2	50.8