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Population exposure to ionizing radiation from medical examinations in France

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ABSTRACT. This study was carried out to update data concerning both the nature and the frequency of X-ray diagnostic procedures and to reassess the associated *per caput* effective dose in France, given that the only nationwide survey was carried out over 15 years ago. Relevant data concerning examinations in conventional radiology, computed tomography, interventional radiology and nuclear medicine were obtained for the year 2002 from two main sources: the main health insurance records for private practices and the statistics of healthcare establishments on hospital activity. Doses associated with different types of examination were obtained from the diagnostic reference levels (DRL) campaign, together with data from the European Commission and from the Health Protection Agency in the UK. The results show that between 55.4 and 65.9 million procedures were performed in 2002 in conventional radiology (one-third for dental) and between 4.2 and 6 million in computed tomography. There were 850 000 and 900 000 procedures in nuclear medicine and interventional radiology respectively. Conventional radiology accounts for 90% of the total number of procedures but only 37% of the collective dose, whereas examinations in computed tomography account for 8% of total examinations but 39% of the collective dose. Examinations in nuclear medicine and interventional radiology account for 2% of procedures but 7% and 17% of the collective dose respectively. Finally, the *per caput* effective dose in 2002 was between 0.66 and 0.83 mSv.

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Radiation exposure related to X-ray diagnosis procedures is the main man-made source of ionizing radiation exposure for the population. The average *per caput* effective dose calculated in a given country, as well as the number of diagnostic examinations performed in a country, are global indicators and provide key information for monitoring medical radiation exposure at the population level. They serve to estimate the impact of the different sources of ionizing radiation at the national level and to make both historical and international comparisons. They can also be used to estimate the contribution of medical exposure to ionizing radiation compared with exposure to natural or other man-made sources of radiation. In the particular field of medical exposure to ionizing radiation, they serve to compare doses resulting from different types of examination (conventional radiology or computed tomography, for example). Such indicators provide useful information for determining priorities in terms of dose reduction and improving patient protection, as required by European directive EURATOM 97/43.

To understand practices at the national level, it is necessary to define the nature and frequency of the various types of examination and the mean effective dose associated with each one of these procedures. In France, the only nationwide survey on medical radiographic practices was carried out more than 20 years ago [1–3]. This study covered all practices apart from dental radiology, chest radiography for screening, computed tomography, nuclear medicine and conventional radiology at healthcare establishments linked to the Ministry of Defence. It was carried out at 386 public hospitals and private clinics considered to be representative of the activity in conventional radiology at the national level. Key examination parameters were assessed at radiological facilities considered to be representative of French facilities. Dosimetric measurements were also taken. Maccia et al [4] published the results of this study in 1988, and takes a synthetic approach. The total number of procedures performed in conventional radiology in 1982 rose to 45.4 million and the *per caput* dose was estimated as 1.58 mSv, based on tissue-weighting factors, as described in publication no. 26 of the International Commission of Radiological Protection (ICRP) [5]. In 1988, a new national survey was carried out using the same method as that used in 1982 with a view to updating the data relating to the frequency of procedures only. Compared with 1982, the average number of procedures per inhabitant and per year had risen slightly from 0.82 to 0.97. *Per caput* effective dose was updated only in 1993 [6] based on the number of procedures from the 1988 survey and the parameters of dose data used in 1982. The calculations took account of new tissue-weighting factors contained in ICRP publication no. 60 [7]. The *per caput* effective dose of medical origin for the French population was evaluated as 1.02 mSv. Subsequent to this study, only

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some smaller, targeted studies have been performed. The results and conclusions of these studies have been published only in internal reports, such as the study commissioned by the French hospital administration directorate in 1997, which constitutes the first and the only study undertaken in France on computed tomography.

No consistent recent data concerning both the nature and the frequency of radiographic diagnostic procedures and associated effective dose are currently available in France. With the implementation of European Directive 97/43, knowledge of practices in medical radiology is needed and the question of the population dose resulting from medical X-ray examinations has again been raised, with an added interest in certain subpopulation groups, such as children. Moreover, changes in practices in recent years justify a new study on the question of diagnostic doses.

In order to provide data concerning medical exposure to ionizing radiation in France, a study was carried out in 2005 to assess the nature and frequency of radiological diagnostic procedures and associated doses. This study updates the detailed dose estimate for the year 2002, using institutional data sourced from the French healthcare system for the nature and frequency of examinations and some recent information on patient doses drawn from the diagnostic reference levels (DRL) campaign together with European data. The focus is mainly on exposure during conventional radiological procedures and computed tomography scans. More general data related to nuclear medicine and interventional radiology were also collected in order to evaluate exposure of the French population to ionizing radiation of medical origin as accurately as possible.

Methods

To evaluate the annual French population dose from diagnostic medical examinations, information is required on the nature and frequency and the mean effective dose for each type of examination. Taking account of the difficulty involved in carrying out a national survey, it was decided to test the validity and the limitations of the data already available through various French administrative offices.

Frequency of examinations

In France, radiological examinations may be performed either by registered private practitioners or at hospitals (public or private). For outpatients, almost all examinations entail records for the purposes of reimbursement by the national state health insurance office (CNAM), which provided several databases used for this study. If the examinations are performed at a hospital (public or private), they may or may not entail direct reimbursement by the regional state health insurance office. In fact, examinations may be included in the overall cost of a hospital stay but are necessarily included in records of the hospital's activity. The latter are recorded in the hospital's yearly statistics (SAE). National health insurance (CNAM) data and hospital records are designed to overlap. These two main sources of data were, therefore, checked and analysed.

Data from the national health insurance office

Three sets of data generated from CNAM databases were used for this study. The first two databases were surveys focusing on the use of and a breakdown of medical imaging procedures in general radiology and in dental practice. The third was a database retrieved via a specific request made in the CNAM databases for CT activity.

The first survey was carried out during the first quarter of 2000 and data were then extrapolated in 2002. The results consist of a list of 115 different procedures using the nomenclature of medical procedures (CCAM) and giving the corresponding number of procedures performed. This list covers all radiological diagnosis procedures carried out in conventional radiology or in computed tomography, excluding dental. The aim of the second survey, carried out in 2002, was to estimate, at the national level, the annual frequency of dental procedures performed by registered dental surgeons, general practitioners and dentofacial orthopaedists. Results relating to all procedures performed by dental surgeons and data concerning radiological procedures were retrieved. The major advantage of these data is that they provide the anatomical and technical classification of all the procedures. Thirdly, a specific request was made for data concerning procedures in computed tomography and interventional cardiology that had been reimbursed by the CNAM. The request concerning procedures carried out in computed tomography was made by retrieving procedures coded ''Z19'' (tracking code for computed tomography), including additional information about age but no information about the anatomical area covered by the CT examination.

Statistics on health establishment activity

The annual statistics on health establishment activity are recorded in the ''Yearly Statistics from Health Establishments'' (SAE) database. This contains a yearly statement of activity declared by public or private health establishments. Activity is broken down according to patient status (hospitalized or not) but can also be used to register patients hospitalized outside the hospital where the examination was performed. Data used for this study related to the year 2002.

To check the consistency of this information, the results of these two major sources were compared with those from two other, more limited, studies:

(i) A study on data taken from the Ile-de-France Agency for Hospitalization's files on renewal of authorization for heavy equipment covering 11 healthcare centres. This provides information on the healthcare system and changing practices.

(ii) Data from the French Society of Cardiology and, in particular, from a working group studying interventional cardiology (GACI), which recorded the activity of all French cardiology units.

In order to synthesize these different sources of data, the main methodological difficulty remains the existence of an overlap between the institutional databases. Actually, examinations carried out at health establishments for outpatients may either be recorded as part of the establishment's activity or be considered as an external procedure reimbursed by the CNAM. On the other hand, a procedure carried out at a private centre, for a patient hospitalized in a public institution, may be recorded in relation either to the private entity or to the public entity. The overlap between the activity of the establishments and the procedures that are reimbursed is impossible to evaluate quantitatively and this explains why we proceeded according to two main assumptions corresponding to (i) a ''low hypothesis'' for which we supposed that there is a complete overlap between CNAM data and SAE data for the examinations carried out for outpatients. According to this assumption, the sum of procedures recorded in the CNAM database and procedures carried out for the establishment only in the SAE is retained; (ii) a ''high hypothesis'' where we supposed that there is no overlap between the CNAM database and the SAE database (for the health establishment and outside the establishment). According to this assumption, it is advisable to add the values of the two data sources. Consequently, the ''low hypothesis'' may be considered as the minimum possible number of examinations that are carried out in France, whereas the ''high hypothesis'' is equivalent to the maximum possible number of examinations. However, it is reasonable to think that the actual number of radiological procedures performed in France lies somewhere between the two.

Insofar as interventional cardiology is concerned, the GACI data appeared more comprehensive than the SAE and CNAM data, so we decided to use these data.

Doses associated with examinations

Currently few data are available about the doses associated with examinations in France. The most recent data, and thus the most in line with current practices, derive primarily from the results of the French 2001–2003 measurement campaign to establish diagnostic reference levels (DRL). In conventional radiology, these results relate to four common examinations: chest radiography, radiography of the abdomen without preparation, posteroanterior view of the lumbar spine and lateral view of lumbar spine. In computed tomography, the results also relate to four examinations: standard chest, high-resolution chest, abdomen and skull [8]. Based on the characteristic entrance surface dose (ESD) in conventional radiology, the corresponding effective doses were calculated using XDOSE software (National Radiation Laboratory, PO Box 25099, Christchurch, New Zealand). The mean effective dose for chest radiography, radiography of the abdomen without preparation, posteroanterior view of the lumbar spine and lateral view of the lumbar spine was found to be 0.05, 0.58, 0.83 and 0.39 mSv, respectively. Based on the characteristic dose length product (DLP) in computed tomography, the corresponding effective doses were calculated using the conversion factors recommended in ''European guidelines on quality criteria for computed tomography (EUR 16 262 EN)'' [9]. Values published in the European Commission report, ''Radiation protection 118'' [10], were applied for eight types of examination: skull and/or facial bones and/or sinus (three views or more) – dental panoramic excluded; skull and/or facial bones and/or sinus (one or two views) – maxilla-dental panoramic excluded; intravenous urography; oeso-gastro-duodenum with Ba; Ba follow-through/small bowel meal; pelvis and/or sacro-iliac joint (one or two views) – hip excluded; pelvis and/or hip(s) (three or four views); and pelvis and/or hip(s) (five views or more). For other examinations, values contained in the National Radiological Protection Board (NRPB)-W4 report of March 2002 [11] were used.

Calculating a collective procedure dose

A ''total dose'' per examination type was calculated by multiplying the number of procedures by the mean effective dose associated with each type. The sum of these total doses per examination type is a value similar to the collective dose. This quantity was called ''collective procedure dose'' and defined as the sum of all the doses delivered by all of the procedures carried out.

Calculating the per caput *effective dose*

The *per caput* effective dose is obtained by dividing the collective procedure dose by the population of France for the same year, *i.e.* 2002. The population of France was 61.4 million according to the National Institute for Statistics and Economic Studies (INSEE). The *per caput* effective dose was also calculated according to each of the two hypotheses.

Results

Conventional radiology

According to the two hypotheses, between 55.4 and 65.9 million procedures were performed in 2002 (Table 1). One-third of these procedures were dental examinations and around 80% of dental procedures were intraoral retroalveolar and/or retrocoronal examinations. Analysis of the data concerning all examinations, excluding dental radiology, makes it possible to evaluate the annual number of radiology procedures as between 36.9 and 47.5 million. In the results of this calculation, the breakdown of conventional radiology procedures showed that radiography of the lung was still the most frequently performed procedure (4–5.3 million a year) followed by bilateral mammograms (from 4.0 to 5.1 million, screening mammograms excluded). The total number of radiographic examinations of the limbs ranged from 12.2 to 15.8 million, *i.e.* one-third of conventional examinations, dental excluded.

The collective procedure dose as a result of conventional radiology examinations was estimated at between 14 600 and 18 700 Sv for the year 2002 (Table 1). The total dose attributed to spinal radiography accounted for 50% of the total, whereas radiography of the abdomen, pelvis and breast accounted for 18%, 15% and 12% respectively of the collective procedure dose.

Table 1. Number of procedures in conventional radiology and induced total dose in France in 2002, according to the high and low hypotheses

Procedure	Number in 2002		Total dose per examination type (mSv)	
	Low hyp	High hyp	Low hyp	High hyp
Head and neck	**2001664**	**2572289**	**133495**	**171551**
Skull and/or facial bones and/or sinus (three views or more) – dental panoramic excluded	980267	1259717	68619	88180
Skull and/or facial bones and/or sinus (1 or 2 views) – macilla-dental panoramic excluded	754052	969013	52784	67831
Neck soft tissue (larynx, pharynx, trachea)	185085	237849	11105	14271
Temporo-mandibular joint	82260	105710	987	1269
Chest	**4908292**	**6307523**	**245415**	**315376**
Lung	4085690	5250418	204285	262521
Chest bones	815747	1048296	40787	52415
Chest dynamic	6855	8809	343	440
Abdomen/pelvis	**2201225**	**2828739**	**2659443**	**3417585**
Abdomen (without preparation)	1350795	1735873	779409	1001599
IVU	342904	440657	857260	1101643
Hysterosalpingography	198949	255664	238738	306797
Oeso-gastro-duodenum with Ba	95970	123329	287911	369987
Cysto-urethrography	82311	105776	123467	158664
Ba follow-through/small bowel meal	41130	52855	123390	158566
Pelvimetry	34275	44046	27420	35237
Colon Ba enema	27420	35237	197424	253705
Radiography of the contents of the gravid uterus	13710	17618	7911	10166
Cysto-urethrography per transcutaneous puncture	6906	8875	8287	10650
Dynamic colpocystorectography	6855	8809	8226	10571
Spine	**6903050**	**8870937**	**7206592**	**9261012**
Lumbar spine (4 views or more)	1706950	2193558	4096679	5264539
Cervical spine (3 views or more)	1508103	1938025	105567	135662
Lumbar spine (1 to 3 views)	1480683	1902789	1776820	2283346
Thoracic spine	1268178	1629703	1014542	1303763
Sacrum or coccyx	370171	475697	62929	80869
Whole spine (2 views)	198795	255467	27831	35765
Whole spine (1 view)	185085	237849	12956	16649
Whole spine (2 views + local view)	102825	132138	102825	132138
Cervical spine (1 or 2 views)	75405	96901	5278	6783
Vertebral arthrography	6855	8809	1165	1498
Pelvis/hips	**3777112**	**4853872**	**2234734**	**2871801**
Pelvis and/or sacro-iliac joint (1 or 2 views) – hip excluded	2933946	3770340	2053762	2639238
Pelvis and/or hip(s) (3 or 4 views)	603241	775210	180972	232563
Pelvis and/or hip(s) (5 views or more)	239925	308322		
Limbs	**12284231**	**15786163**	**282959**	**363627**
Knee (3 or 4 views)	1576653	2026118	3942	5065
Foot (1 to 3 views)	1562943	2008499	938	1205
One hand or fingers	1213337	1559230	607	780
Knee (5 views or more)	1041962	1338999	2605	3347
Scapula and/or shoulder (3 or 4 views)	973412	1250907	9734	12509
Ankle (1 to 3 views)	843218	1083598	1686	2167
One or two hips (1 or 2 views)	733486	942585	256720	329905
Wrist (3 views or more)	671791	863302	336	432
Knee (1 or 2 views)	658081	845684	1645	2114
Wrist (1 or 2 views)	568966	731164	284	366
Ankle (4 views or more)	438721	563789	263	338
Scapula and/or shoulder (1 or 2 views)	301621	387605	3016	3876
Leg	205650	264276	411	529
Elbow (1 or 2 views)	198795	255467	99	128
Scapula and/or shoulder (5 views or more)	178230	229039	89	115
Elbow (3 views or more)	164520	211421	82	106
Foot (4 views or more) – podometric study excluded	157665	202612	79	101
2 hands and /or 2 wrists (1 view on the same film)	123390	158566	62	79
Femur	102825	132138	51	66
One or two lower limbs using large source-to-film distance	95970	123329	48	62
Forearm	95970	123329	48	62
Knee arthrography	89115	114520	45	57
Upper arm	68550	88092	34	44

Table 1. *Continued.*

Procedure	Number in 2002		Total dose per examination type (mSv)	
	Low hyp	High hyp	Low hyp	High hyp
Shoulder arthrography	54840	70474	27	35
Podometric study	54840	70473	55	70
Bone mineral densitometry (2 sites, using biphotonic method)	27420	35237	14	18
Elbow arthrography	20565	26428	10	13
Skeletal survey	20565	26428	10	13
One or two upper limbs using large source-to-film distance	13710	17618	7	9
Two lower limbs using large source-to-film distance	6855	8809	3	4
Hip arthrography	6855	8809	3	4
Whole skeleton in child	6855	8809	3	4
Joint cartilage of long bones	6855	8809	3	4
Breast	**4867469**	**6255062**	**1737124**	**2232334**
Two breasts – screening mammograms excluded	4010490	5153780	1483881	1906898
Screening	520981	669500	192763	247715
One breast	335998	431782	60480	77721
Dental	**18426727**	**18426727**	**113655**	**113655**
Intraoral (1 or 2 views)	14637479	14637479	73187	73187
Panoramic	2267277	2267277	22673	22673
Intraoral (3 to 5 views)	934994	934994	14025	14025
Skull and facial bones for orthodontal diagnosis	379107	379107	1137	1137
Intraoral (6 to 8 views)	91663	91663	1375	1375
Intraoral (12 views or more)	42611	42611	639	639
Skull and facial bones (2 views) for orthodontal diagnosis	41660	41660	208	208
Intraoral retro-alveolar and/ or retro-coronal (9 to 12 views)	18267	18267	274	274
Occlusal	13669	13669	137	137
Total	**55369776**	**65901314**	**14613422**	**18746941**

Computed tomography

Of the 106 types of radiology procedure recorded in the CNAM database, 29 concerned computed tomography. Based on the results of a specific search request, it was possible to find out the total number of procedures that entailed reimbursement in 2002, *i.e.* around 2.2 million. The total number of procedures was calculated for different patient age groups. In 2002, 58% and 33% of computed tomography scans were performed on patients between 30 and 65 years old and over 65 years old respectively. Less than 1% were performed on children under 15 years old. The total number of computed tomography examinations performed in hospitals was 3.8 million, according to the national statistics of health establishments. Thus, the total number of examinations was between 4.2 million for the low hypothesis and 6 million for the high hypothesis (Table 2). Head and spine examinations accounted for 37% and 26%, respectively, of the total. Examination of the abdominal region, chest and limbs represented 18%, 12% and 7% of the total, respectively.

Doses associated with three of the four examinations included in the first DRL campaign in France were calculated using DLP measurements. These four examinations were standard chest, high-resolution chest, abdomen and skull. The mean effective doses related to these examinations were then determined using the conversion factor given in the European guidelines on quality criteria for computed tomography (EUR 16 262 EN) [9] except for high-resolution chest for which no conversion factor was found in the European guidelines. Thus, data used for standard chest, abdomen and skull examinations were 5.5, 6.7 and 1.8 mSv, respectively. The value for skull examinations was applied to 8 of the 10 examinations listed in the category ''HEAD''. For the other two examinations in this category, namely examinations of neck soft tissues (with or without contrast product), values were taken from NRPB-W4 report [11]. Concerning chest and abdomen/pelvis examinations, French values from the DRL campaign were applied for all procedures except for pelvimetry for which the NRPB value was applied. Finally, the effective dose values concerning spine and limb examinations were all taken from the NRPB-W4 report. The collective procedure dose owing to examinations for computed tomography for the year 2002 was then estimated as 14 600 Sv for the low hypothesis and 20 800 Sv for the high hypothesis (Table 2). The total dose for abdomen/pelvis and spine examinations accounted for 61% of the total, whereas computed tomography of the chest and head each accounted for 19% of the collective procedure dose received from computed tomography, and limbs for less than 1%.

Diagnostic examination in nuclear medicine

The only data collected on nuclear medicine procedures are those available in the healthcare establishment statistics (SAE database). The total number of

Table 2. Number of procedures in computed tomography and induced total dose in France in 2002, according to the high and low hypotheses

Procedure	Number in 2002		Total dose per examination type (mSv)	
	Low hyp	High hyp	Low hyp	High hyp
Head	**1541819**	**2188894**	**2798737**	**3973316**
Skull bones and soft tissues without injection – petrous bone excluded	368676	523403	663617	942125
Skull bones and soft tissues with injection – petrous bone excluded	581027	824874	1045849	1484774
Facial bones without injection	346332	491682	623398	885027
Facial bones with injection	11172	15861	20110	28549
Petrous bone or internal auditory meatus without injection	55860	79303	100548	142746
Petrous bone or internal auditory meatus with injection	100548	142746	180986	256943
Sialography	33516	47582	60329	85648
Brain vessels	11172	15861	20110	28549
Neck soft tissues with injection	22344	31721	55860	79303
Neck soft tissues without injection	11172	15861	27930	39652
Chest	**513912**	**729592**	**2826517**	**4012756**
Chest with intravenous injection	368676	523403	2027719	2878716
Chest without intravenous injection	122892	174468	675906	959572
Chest and/or heart vessels	22344	31721	122892	174468
Abdomen/pelvis	**770951**	**1094505**	**4439195**	**6302245**
Abdomen or pelvis without injection	67032	95164	449115	637600
Abdomen and pelvis without injection	33599	47700	225115	319592
Abdomen or pelvis with injection	290472	412378	1946163	2762933
Abdomen and pelvis with injection	245784	348935	1646753	2337866
Pelvimetry	111720	158607	22344	31721
Abdomen and/or pelvis vessels	22344	31721	149705	212533
Spine	**1106111**	**1570327**	**4424446**	**6281308**
Spine one part without injection	904932	1284716	3619729	5138865
Spine one part with injection	178835	253889	715341	1015557
Spine more than one part without injection	11172	15861	44688	63443
Spine more than one part with injection	11172	15861	44688	63443
Limbs	**290472**	**412379**	**145236**	**206188**
Part of upper limb and/or joint without injection	44688	63443	22344	31721
Part of upper limb and/or joint with injection	44688	63443	22344	31721
Part of lower limb and/or joint without injection	89376	126886	44688	63443
Part of lower limb and/or joint with injection	22344	31721	11172	15861
Upper limb arthrography	78204	111025	39102	55512
Lower limb arthrography	11172	15861	5586	7930
Total	**4223267**	**5995697**	**14634130**	**20775815**

procedures in 2002 was 850 000, including both radioisotope scans and positron emission tomography (PET), which accounted for 0.5% of the total (Table 3). Based on unpublished data (F. Paycha, personal communication), it was found that 50% of radioisotope scans could be bone scans, whereas 25%, 15% and 12% of these could be radioisotope scans of the heart, lung and thyroid, respectively. In the absence of detailed data regarding the total number of each type of radioisotope scan, it was not possible to evaluate the total effective dose due to procedures in nuclear medicine precisely. The values calculated by the European Community were used and a mean effective dose of 4 mSv was calculated and used for each radioisotope scan whereas a value of 5 mSv was used for examinations of the skull by PET. The collective procedure dose due to nuclear medicine examinations therefore came to 3 400 Sv for the year 2002 (Table 3).

Interventional radiology examinations

In the case of examinations performed at interventional radiology units in hospitals, the SAE data distinguish between ''heart'' and ''non-heart'' vessel procedures. There were around 700 000 such procedures in 2002. Moreover, 185 000 procedures were performed mainly in electrophysiology but also in neuroradiology and lithotripsy. Compared with the other types, interventional radiology procedures are mainly performed at health establishments. Lastly, the total number of procedures was around 900 000 in 2002 (Table 3). As in the case of nuclear medicine, in the absence of detailed data regarding the different types of procedure and the difficulty of defining a mean effective dose, the effective dose given in the NRPB-W4 report was used. Lastly, the collective procedure dose due to interventional radiology came to around 7 800 Sv for the year 2002 (Table 3).

Table 3. Number of procedures in nuclear medicine and interventional radiology, in France, in 2002

Procedure	Number in 2002	Total dose per examination type (mSv)
Nuclear medicine		
Scintigraphy	845698	3382792
PET	3922	19610
Total	849620	3402402
Interventional radiology		
Neuradiology	12183	69443
Vascular	354740	3192660
Heart	352553	3172977
Electrophysiology	144370	1299330
Lithotripsy	28539	37101
Total	892385	7771511

Frequency of examinations and collective procedure dose in France in 2002

The total number of procedures and the collective procedure dose were calculated according to the two hypotheses. According to the low hypothesis, 61.3 million procedures were performed, whereas the high hypothesis gave 73.6 million. The collective procedure dose came to between 40 407 Sv and 50 675 Sv depending on which hypothesis was used. Conventional radiology accounted for 90% of all procedures but for only 37% of the collective procedure dose, whereas examinations in computed tomography accounted for only 8% of all examinations but for 39% of the collective procedure dose (Figure 1). Examinations performed in nuclear medicine or in interventional radiology accounted for 2% of the total number but for 7% and 17% of the collective procedure dose respectively. An alternative analysis of the results is shown in Figure 2 with the breakdown according to anatomical region for procedures performed in conventional radiology and computed tomography and compared with the total number of examinations performed in nuclear medicine and interventional radiology. The most frequent procedures are conventional dental radiographs and radiographs of limbs. These are followed by examinations of the spine, then examinations of the abdomen and then chest examinations. However, spine and abdomen examinations deliver the highest part of the collective procedure dose, followed by interventional radiology procedures (Figure 2).

Per caput *dose estimation*

According to the low hypothesis, the annual collective procedure dose received by the whole of the French population amounted to 40 407 Sv. The *per caput* dose would thus be 0.66 mSv per inhabitant in 2002 given that the population of France is 61.4 million (INSEE). Similarly, according to the high hypothesis, the *per caput* dose due to medical exposure would be 0.83 mSv. In this total contribution of medical examinations to exposure of the French population, conventional radiology and computed tomography each accounted for a little more than a third of the total. Lastly, nuclear medicine and interventional radiology procedures together made up less than one-third of the total (Table 4).

Trends in French medical practices in radiology over the last 20 years

The results of our evaluation for 2002 are compared with those of previous evaluations (Table 5). Since 1980, three national surveys have been carried out, in 1982 [1–3], 1988 [12] and 1994 [4, 13]. Insofar as the collective dose is concerned, only the investigations of 1982 and 1988 have been published, whereas data on exposure in 1994 concerning the collective dose appear in only one report submitted to France's Directorate-General for Health [4]. However, the methodology used for the latter study and the results concerning the number of procedures are given in a public expert's report published by the INSERM [13]. The methodology used for the previous three studies was based on a survey of radiology units. Our method involved taking account of all the examinations recorded in the institutional databases. Although it seems difficult to compare results obtained using these two different methods, because of the skew involved, it is reasonable to think that, nationally, under- and overestimating the number of declared procedures balances the figures out. Consequently, any difference in the average individual effective dose since 1982 can be examined to analyse trends; the number of procedures was standardized per 1000 people (Table 5). Only examinations studied at the time of the four investigations were factored in.

A significant reduction in the number of conventional radiography examinations without preparation has been observed: chest radiographs (down 63% between 1982 and 2002) and skull radiographs (down 42% between 1982 and 2002). The number of radiographs of the abdomen remained stable, or even increased (up 17% between 1982 and 2002), and an increase in the number of radiographs of the spine (up 68% between 1982 and 2002), together with a distinct drop, by a factor of between 5 and 10, in the number of examinations involving injection of contrast agents and triple the

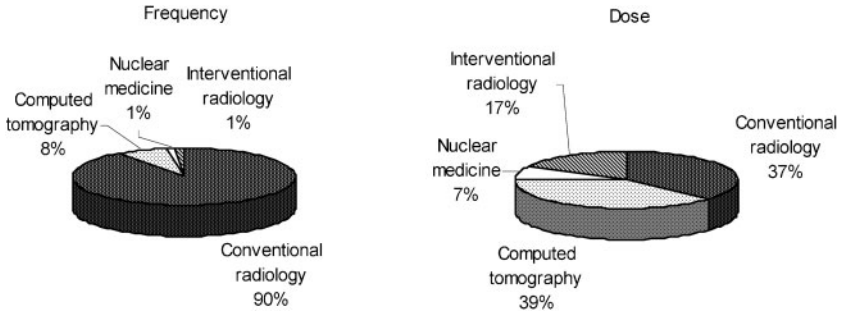

Figure 1. Frequency and dose for conventional radiology, computed tomography, nuclear medicine and interventional radiology as a percentage of total procedures or collective procedure dose.

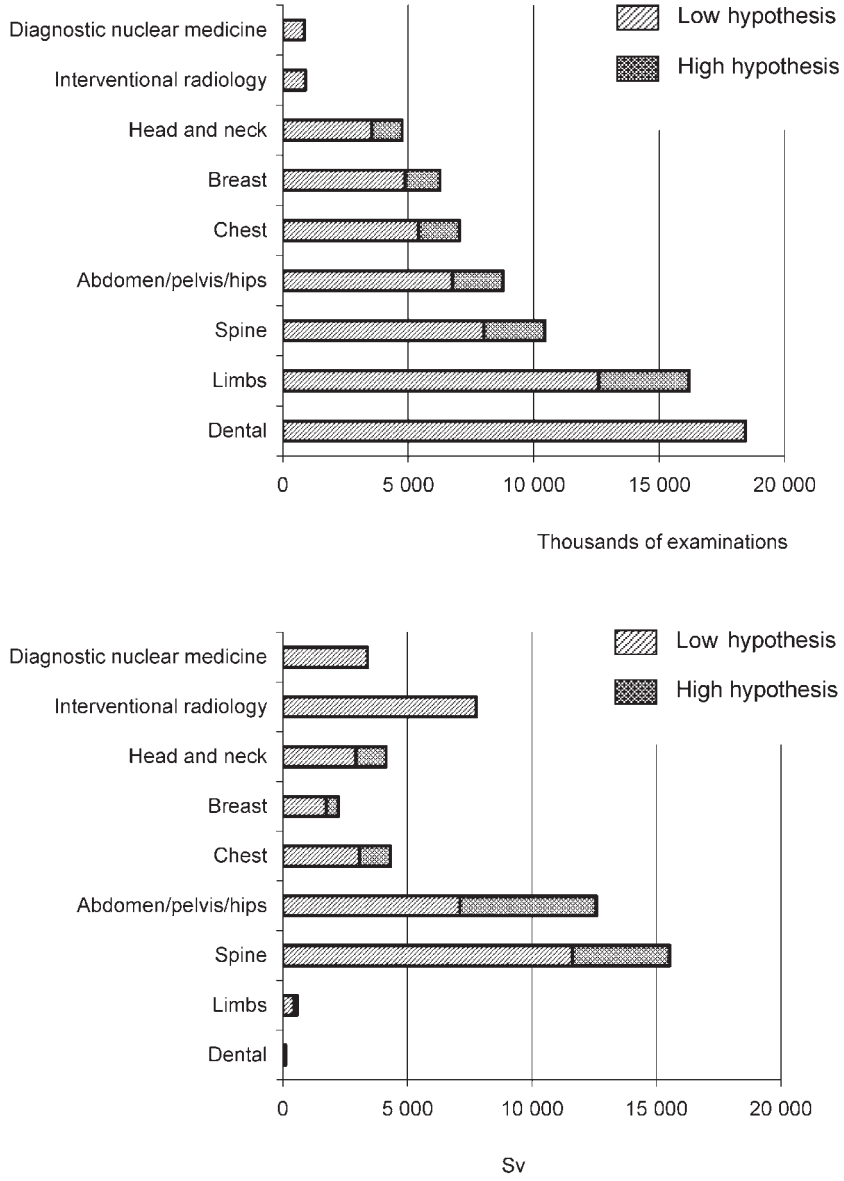

Figure 2. Annual frequency and total dose per examination type in France in 2002.

number of computed tomography procedures in the last 15 years, were also noted. A significant increase in the number of mammograms between 1982 and 2002 was generally observed, although the total number seems to have dropped between 1994 and 2002. Finally, the most remarkable point of this ''historical sequence'' is the rise in computed tomography and the drop in examinations using contrast agents.

Table 4. *Per caput* dose estimation in France in 2002

Procedure	Dose (mSv year^{-1})
Conventional radiology	0.24–0.31
Computed tomography	0.24–0.34
Nuclear medicine	0.06
Interventional radiology	0.13
Total	0.66–0.83

Discussion

Estimating the impact of exposure from medical procedures on the exposure levels of the French population to ionizing radiation implies a need to define both the nature and the number of the procedures performed and a mean effective dose for each examination type. First, to define the nature and frequency of the examinations, the decision was taken to use the institutional databases, which had the advantage of providing, *a priori*, data collection at the national level. Several categories of data were examined and it was then possible to check their consistency and also ensure that the data were as exhaustive as possible. The operational limitations of these different sources are, firstly, the quality of information collection and, secondly, the possible redundancy of information. The quality of administrative information on these activities may suffer from an excess of declarations or duplicate declarations, but the controls applied during the transmission of information and validation by the DREES (French

Table 5. Changes in French medical practices in radiology over the last 20 years (procedures per 1000 inhabitants)

Procedure	1982 survey	1988 survey	1994 estimation	2002 – this study	
				Low hypothesis	High hypothesis
Conventional radiology					
Skull	73	77	69	33	42
Chest	281	343	252	80	103
Spine	86	93	100	113	145
Abdomen - pelvis	91	98	128	84	107
Limbs	183	223	281	200	256
Mammography	5	34	152	80	102
Oeso-gastro-duodenal transit (with Ba)	36	23	19	3	3
IVU	36	16	12	6	7
Other	29	61	66	4	8
Total	820	968	1079	603	773
Computed tomography					
Head and neck			17.7	25.2	35.8
Chest			5.3	8.3	11.8
Abdomen - pelvis			8.4	12.5	17.7
Spine				18.0	25.5
Limbs			1.8	4.7	6.7
Other			1.1		
Total			34.3	68.7	97.5
Per caput dose mSv/inhabitant/year	1.58[a]	–	1.15	0.66	0.83

[a]With tissue-weighting factors from ICRP publication 26.

Directorate for Research, Studies, Evaluation and Statistics) help to minimize such uncertainty.

Concerning the dose associated with each procedure, there are very few French data on the subject. Only dosimetric measurements taken recently, to establish diagnostic reference levels, were used. Considerable variation was observed between centres, by as much as a factor of 5 or 6. In the absence of data sourced from French healthcare centres, the effective dose used for each examination type was taken from European studies or medical literature and, in particular, NRPB data.

The collective procedure dose is calculated as the sum of the individual effective doses of all procedures carried out on this population. It is an indicator used to monitor changes in the practice on a national scale and to make comparisons between countries. By dividing the collective procedure dose by the number of inhabitants that make up the population, one obtains a *per caput* dose, the significance of which may well be debatable. Indeed, the distribution of radiographic examinations across the population is not homogeneous, but, on the contrary, extremely asymmetrical. A very small percentage of people undergo the large majority of radiographic examinations and therefore receive a large proportion of the dose. This exposure is, of course, related to a pathological condition. Indeed, for a population with no chronic pathologies, exposure is specific, and mainly limited to dental examinations or those made as a result of trauma. A significant percentage of examinations and of the dose is concentrated on patients with chronic diseases, and this is generally over several years. To date, this analytical approach to the distribution of radiographic examinations remains underdeveloped. The results of this study indicate that around 65% of the collective procedure dose can be ascribed to examinations in computed tomography, nuclear medicine or interventional radiology and is received by 8 million people maximum. Thus, the *per caput* dose for these people is 4.2 mSv. Furthermore, the effective dose is a measurement of exposure affecting the entire body of the individual. The effective dose obtained if we apply tissue-weighting factors can be used to compare the total impact of radiological procedures and the effect on different areas of the body. Moreover, the impact of certain procedures may also be weaker in the adult than in a younger, and thus more radiosensitive, person, such as a child. Despite this potential constraint, the collective dose (or the collective procedure dose as defined in this paper) as well as the distribution of radiological procedures serves to compare practices in countries that have similar standards of healthcare.

A comparison of the estimated French annual *per caput* dose with similar data for other countries based on information reported by UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation), or other data, may be made. Actually, except for UNSCEAR data, only a few sources of information are referenced. Data published in the last UNSCEAR report in 2000 [14] concerned results obtained in the 1990s, whereas other reports concern results for the late 1990s and the beginning of the new millennium. In countries that are very similar to France, various data have been collected about the frequency of examinations and the annual *per caput* effective dose. So, the number of examinations per inhabitant and per year varied from 0.48 for the UK [15] to 1.7 for Germany [16]. The annual *per caput* effective dose varied from 0.38 mSv for the UK [15] to 2 for Germany [16], with intermediate values for The Netherlands (0.59 mSv) [17] and Switzerland (1.34 mSv) [18]. French values determined in this study also fall within these intermediate values. This comparison highlights significant differences between very similar countries but these differences may be attributed to the number of procedures performed rather than to differences in examination doses, as the various teams

use NRPB dose data [19]. In the particular area of nuclear medicine, French results determined a frequency of 14 procedures per 1000 population, whereas the estimate for the UK was 11 procedures per 1000 population [20]. However, comparing data for different countries is difficult because the methods used to code procedures and to calculate the number of procedures performed differ from country to country and underline the necessity of an internationally accepted protocol to evaluate patient exposure.

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