Paper

NATION-WIDE SURVEY ON RADIATION DOSES IN DIAGNOSTIC AND INTERVENTIONAL RADIOLOGY IN SWITZERLAND IN 1998

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Abstract—**A nation-wide survey on radiation doses in diagnostic and interventional radiology was conducted in Switzerland in 1998 aiming at establishing their collective radiological impact on the Swiss population. The study consisted on the one hand of surveying the frequency of more than 250 types of examinations, covering conventional radiology, mammography, fluoroscopy, angiography, interventional radiology, CT, bone densitometry, conventional tomography and dental radiology. On the other hand, for each type of examination the associated patient dose was established by modeling. The results of this study show that about 9.5 million diagnostic and interventional examinations are performed annually in Switzerland (1.34 per caput) and that the associated annual collective dose is of the order of 7100 person.Sv (1.0 mSv per caput). Switzerland is similar to other European countries in terms of the frequency of examinations and the collective dose. Health Phys. 83(1):46–55; 2002**

Key words: diagnostic radiology; medical radiation; modeling, dose assessment; dose, population

INTRODUCTION

In countries with similar health level as Switzerland, the average dose of ionizing radiation to the population from medical exposure is estimated to about 0.2–2 mSv y^{-1} (UNSCEAR 2000). This represents the highest contribution of man-made irradiation and around a quarter of the total dose received by the population.

During the past decades and particularly in recent years, this fact has stimulated a great number of studies in different countries aiming at establishing the frequencies of the different types of examinations as well as the associated radiation doses (Kendall et al. 1980; Wall et al. 1986; Shrimpton et al. 1986; Maccia et al. 1988; Benedettini et al. 1989; NCRP 1989; Shrimpton et al. 1991; NRPB 1992; Rueter et al. 1992; Serro et al. 1992; Maruyana et al. 1992; Staniszewska 1993; Bernhardt et al. 1995; Servomaa et al. 1995; Leitz et al. 1995; Poletti 1996; Liu et al. 1996; Fortuna and Zdesar 1996; Hart et al. 1996; Kalmykov et al. 1997; Van Unnik et al. 1997; Olerud and Saxebol 1997; Iwai et al. 1998; Goddad and Al-Farsi 1999; Bonnin and Lacronique 1999; Tanner et al. 2000; Li et al. 2001). The United Nations Scientific Committee for the Effects of Ionising Radiation, UNSCEAR, regularly issues a thorough report on the national surveys dealing with medical irradiation from around the world. The last UNSCEAR report was published in 2000 (UNSCEAR 2000).

The interest of the international scientific community for medical exposure of the public and particularly from diagnostic and interventional radiology has been reflected during the past decade by several scientific meetings: the workshop organized by the Commission of the European Communities in 1993 (Contento et al. 1995), the seminar organized by the German Radiation Protection Commission (SSK 1995), and the Montpellier International Conference on Radiation Protection and Medicine held in 1995. During the last international congress of the International Radiation Protection Association held at Hiroshima in 2000, several sessions were dedicated to radiation protection for medical exposure and especially for interventional radiology (Duftschmid et al. 2000). More recently, the International Atomic Energy Agency has organized in Malaga an international conference fully dedicated to the radiological protection of patients in diagnostic and interventional radiology (IAEA 2001).

Switzerland has a long tradition in this field going back over 40 y (Zuppinger et al. 1961; Poretti et al. 1971; Mini and Poretti 1984; Mini 1992). The last Swiss survey on medical exposure was undertaken in 1992, but no evaluation of the collective dose was made. Since then, several factors associated with demographic evolution, with changing indications for examinations and the techniques used, have altered the average dose to the

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population. A new evaluation of the latter quantity was therefore useful.

The survey described in this report, like the previous ones, aimed at determining the radiation doses delivered in Switzerland by the various radiological examinations (diagnostic and interventional), the frequencies of these examinations as a function of the gender and the age of the patient, and the overall impact of diagnostic and interventional radiology on the Swiss population. It also aimed at investigating the variation of medical practice concerning the use of x-ray examinations and formulating, if necessary, recommendations for dose reduction.

METHOD

The study consisted, on the one hand, of surveying a large number of types of examinations, covering the various modalities in diagnostic and interventional radiology, and, on the other hand, in establishing by modeling, for each examination type, the radiation dose delivered to the patient. The collective impact has been evaluated by convolution of both types of information, using appropriate radiological risk models. The methodology is sketched in Fig. 1.

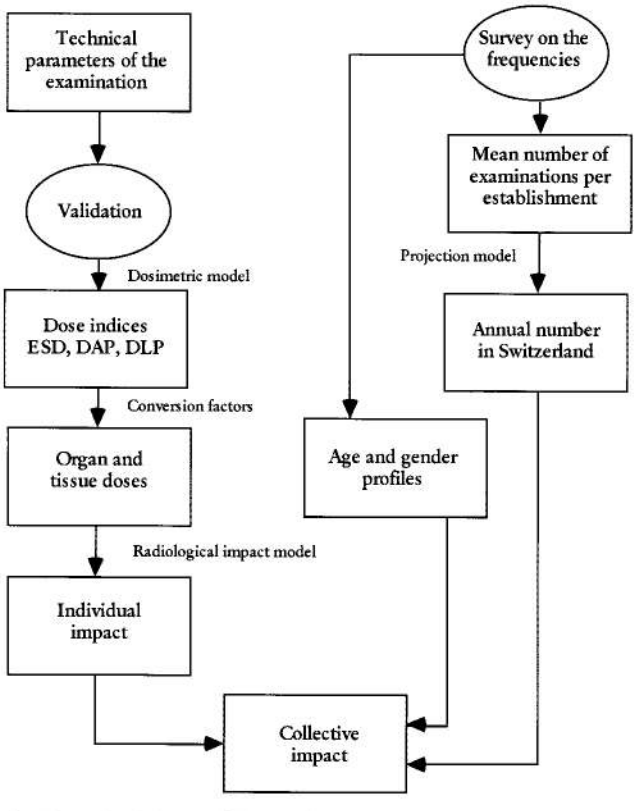

Fig. 1. Methodology of the study.

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

Concerning the dosimetric aspects, a full definition of the various types of examinations was established based on a characterization work performed with the collaboration of the Lausanne University Hospital and validated by several practitioners and radiology departments at university hospitals. From the technical parameters, different dose indices such as the entrance surface dose (ESD) and the dose-area product (DAP) for radiography and fluoroscopy and the dose-length product (DLP) for computed tomography were calculated, and a dosimetric model was established for each radiological modality. These indices were then converted into organ doses and effective dose using dose calculation programs based on appropriate conversion factors: ODS-60 program (Sermovaa et al. 1989) for radiography and fluoroscopy and CT-DOSE program[‡] for computed tomography. The dosimetric study is addressed in more details elsewhere (Aroua et al. 2001).

Regarding the frequency aspects, the survey covered all the categories of establishments which perform radiological examinations in Switzerland: 1) large hospitals with more than 500 beds for which the detailed annual statistics were requested; 2) small hospitals with less than 500 beds that participated in a 2-wk survey; 3) medical practitioners (generalists and specialists), dental practitioners, and chiropractors who participated in a 2-wk survey (1 wk for the dentists); and 4) other special establishments (school, penitentiary and military medicine, etc.) for which the overall annual statistics were requested.

More than 3,000 establishments were approached. The general practitioners (including general internists) were randomly sampled at a 20% rate and the dentists at 10%. For all the other categories, the total number of establishments was considered. A geographic stratification was performed using the most recent regionalization system of Switzerland (Schuler et al. 1999).

The detailed information requested concerned the patient's age and sex, the type of health problem of the patient, the aim of the examination, and the severity of the case. Information concerning the radiological equipment and the image receptors was also collected.

[‡] Baddegaard & Jensen. A description of the programme is provided by the Department of Biomedical Engineering, Aarhus University Hospital. Available at http://www.mta.au.dk. Accessed 24 October 2001.

The seasonal variation of the examination frequencies was investigated separately by means of a small-scale survey that covered a sample of 160 participants stratified over the categories of establishments and over the geographic regions. The aim of this study was to determine whether a correction for this variation is necessary or not.

National frequencies were established by extrapolating the collected data after both the sample and the results' representativeness had been demonstrated as explained in detail in the extended report (Aroua et al. 2001) available online at www.hospvd.ch/public/instituts/ira.

The individual and collective impact of diagnostic and interventional radiology, quantified by means of the effective and the collective doses, respectively, were evaluated according to up-to-date radiological risk models (Aroua et al. 2001) accounting for the age and sex of the patient. An estimation of the error on the integral results was made as a combination of the errors associated with all the quantities involved in the calculation.

RESULTS

Response rate

The overall response rate was 60% with about 1,800 participants. This resulted in the collection of 70,000 examinations with detailed information and 2 million examinations from broad annual statistics.

Total annual number of examinations and collective dose

The results of the study indicate that around 9.5 million radiodiagnostic examinations are performed each year in Switzerland, i.e., 1.34 examination per caput. In terms of doses, the associated annual collective dose is of the order of 7,100 person.Sv, which for a population of 7,096,894 (SCRIS 1998) corresponds to an average annual effective dose per caput of 1.0 mSv.

Distribution with examination categories

Table 1 shows the distribution with the categories of examinations of a) the total annual number of examinations, b) the annual frequency of examinations per 1,000 population, c) the total annual collective dose, and d) the mean annual effective dose per caput.

Distribution with the categories of establishments

Table 2 shows the distribution with the types of establishments practising diagnostic and interventional radiology in Switzerland of a) the total annual number of examinations, b) the mean annual number of examinations per establishment, c) the total annual collective dose, and d) the mean collective dose per establishment.

Distribution with the irradiated region of the body

Table 3 presents the distribution of the annual number of examinations over the irradiated region of the body. Five regions with different contributions to the effective dose are considered: head and neck, thorax, abdomen, pelvis, and limbs.

Distribution with the age of the patient and correction of the collective dose

Fig. 2 shows the distribution of the annual total number of examinations and the collective dose with the age of the patient for all examinations. These distributions are compared to the age distribution of the general population. For the elderly the risks associated with an exposure (induction of cancer with a 20-y latency, hereditary disorders in the offspring) are less important than in the case of young people. To account for this risk difference the literature gives different models for reduction of the effective dose. Three models are proposed—model A proposed by Committee 3 of ICRP,[§] model B of BfS (Bernhardt et al. 1996), and model C of NRPB (Shrimpton et al. 1993)—that suggest the use of a

[§] ICRP Committee 3, Minutes of the Würzburg Meeting; 1995.

Table 1. Distribution with the categories of examinations of the annual total number of examinations and their frequency per 1,000 population as well as the annual collective and mean effective doses per caput.

	Annual number			Annual dose		
Category	Total (rounded in thousands)	Per 1,000 population	Fraction (%)	Collective dose (rounded in person.Sv)	Effective dose (μSv per caput)	Fraction (%)
Radiography	4,500	640	48	3,000	410	41
Dental radiology	4,000	580	43	70	10	1
CT	300	46	3.4	2,000	280	28
Mammography	200	31	2.3	40	6.1	0.6
Radiography and fluoroscopy	150	22	1.6	1,200	170	17
Angiography	70	9.9	0.7	500	78	7.8
Interventional radiology	30	3.8	0.3	250	36	3.6
Bone densitometry	30	4.5	0.3	0.04	0.006	0.0
Conventional tomography	10	1.6	0.1	50	6.8	0.7
Total	9,500	1,340	100	7,100	1,000	100

Table 2. Distribution with the categories of establishments of the annual total number of examinations and the mean number per establishment as well as the total collective dose and the mean collective dose per establishment.

Category	Number of establishments	Annual number: Total (rounded in thousands)	Annual number: Per establishment	Fraction (%)	Annual collective dose: person.Sv (rounded)	Annual collective dose: person.Sv per establishment	Fraction (%)
General and internal medicine	3,910	1,500	373	15.8	670	0.17	9.4
Private institutes of radiology	85	250	2,778	2.6	480	5.66	6.7
Small hospitals (<500 beds)	274	2,000	7,497	21.1	3,300	12.1	46.2
Large hospitals (>500 beds)	11	950	85,782	10.0	1,900	172	26.6
Dental medicine	3,750	4,000	1,095	42.1	70	0.019	1.0
Chiropractic	138	60	421	0.6	140	1.04	2.0
Others	1,590	700	440	7.4	580	0.36	8.1
Total	9,758	9,500	977	100	7,100	0.73	100

Table 3. Fraction of the annual number of examinations per irradiated region of the body.

Irradiated region	Category of examinations: Radiography	Radiography and fluoroscopy	Angiography	Interventional	CT	Dental	Special modalities	All
Total number (thousands)	4,500	150	70	30	300	4,000	240	9,500
Head and neck (%)	9.0	0.2	8.9	3.9	36.9	99.9	0.5	48.9
Thorax (%)	35.4	2.1	47.8	58.2	15.6	0	83.9	20.4
Abdomen (%)	3.2	45.3	10.3	14.9	29.8	0	10.1	3.7
Pelvis (%)	13.7	41.9	5.4	2.3	14.2	0	1.3	7.8
Limbs (%)	38.7	10.5	27.6	20.6	3.6	0.1	4.2	19.2

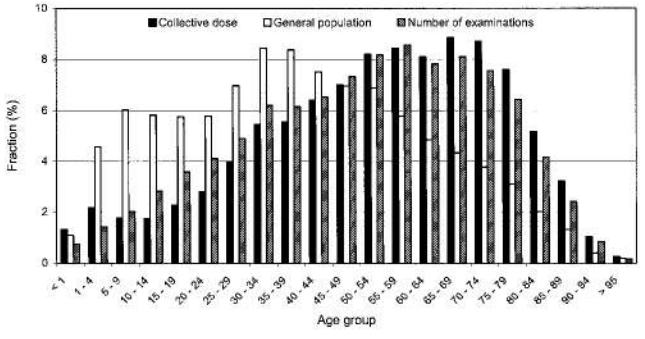

Fig. 2. Distribution of the number of examinations and the collective dose with the age of the patient, compared to the age distribution of the general population.

multiplying factor decreasing with age to weight the effective dose as shown in Table 4. Table 5 shows for the different categories of examinations the ratio of effective dose corrected and non corrected for the age effect according to these three models.

Indication of the examination

This survey was not limited to the radiological impact of diagnostic and interventional radiology although this was the main scope of the study. An attempt to evaluate the diagnostic and therapeutic benefit from the different types of examinations was made. To this end three questions were asked to the participants concerning a) the nature of the health problem, b) the aim of the examination, and c) the severity of the case. The results presented here do not concern large hospitals who provided non detailed statistical data.

Table 4. Age weighting factors according to three different models (see main text for explanation).

Age (y)	Model A	Model B	Model C
0–1	3.0	2.40	1.50
2–5	2.7	2.40	1.50
6–10	2.2	2.40	1.50
11–15	1.7	2.40	1.50
16–40	1.1	1.25	0.75
41–50	0.6	0.44	0.75
51–64	0.4	0.44	0.75
65–69	0.4	0.19	0.75
70+	0.3	0.19	0.15

Nature of the health problem. To the question on the nature of the affection, the participants were asked to answer 1) accident, 2) illness, or 3) other (e.g., preventive examination). Table 6 shows the percentage of the different types of affection for all the participants except large hospitals and dentists, as well as for several medical specialties.

Aim of the examination. To the question on the aim of the examination, the participants were asked to answer

Table 5. Ratio of age-corrected to non corrected effective dose, using three different models (see main text for explanation).

Category of examinations	Model A	Model B	Model C
Radiography	0.58	0.64	0.62
CT	0.49	0.52	0.60
Radiography and fluoroscopy	0.70	0.71	0.68
Angiography	0.54	0.51	0.60
Interventional	0.42	0.40	0.53
Mammography	0.46	0.47	0.70
Dental radiology	0.85	1.02	0.82
Conventional tomography	0.52	0.58	0.67
Bone densitometry	0.40	0.36	0.64
Total	0.57	0.60	0.62

Table 6. Distribution of the answers on the nature of the health problem of the patient undergoing an examination, for selected medical specialties. The percentages are given.

Specialty	Answer "1" Accident	Answer "2" Illness	Answer "3" Other
Hand surgeons	53	47	0
Urologists	1	98	1
ENT	29	71	0
GP	33	62	5
Paediatricians	49	45	6
Total	29	64	7

1) screening for asymptomatic patients, 2) periodic control on high risk patients, 3) to reassure the patient, 4) to confirm or invalidate a diagnostic suspicion, 5) to guide an intervention, 6) to decide on or modify a therapeutic option, 7) to control treatment effectiveness, or 8) other. Table 7 shows the distribution of these answers on the whole number of examinations registered.

Severity of the case. To the question on the severity of the health status, the participants were asked to answer 1) healthy, 2) moderate, 3) severe but not disabling, 4) disabling, or 5) dying, based on an adaptation of a validated severity of illness scale (ASA 2001). Table 8 shows for the overall registered data how the physician appreciates the severity of the health condition of the patient undergoing an examination.

Table 7. Distribution of the answers on the aim of the examination.

Answer	Percentage
"1": screening for asymptomatic patients	6.8
"2": periodic control on high risk patients	12.7
"3": to reassure the patient	3
"4": to confirm or invalidate a diagnostic suspicion	42.8
"5": to guide an intervention	3.9
"6": to decide on or modify a therapeutic option	14.2
"7": to control treatment effectiveness	11
"8": other	4.1
"4" + "6"	1.6

Table 8. Distribution of the answers on the severity of the case.

Answer	Percentage
"1": healthy	68
"2": moderate	23
"3": severe but not disabling	6
"4": disabling	2
"5": dying	0

DISCUSSION

The average annual number of examinations per caput found in this work (1.34) is very close to the ones found in the 1971 and 1978 Swiss surveys (1.35 for 8,555,202 and 8,703,562 total annual examinations in 1971 and 1978, respectively). The total number of examinations is obviously stable, but there are appreciable differences in the frequency of the various types of examinations [for instance a decrease in fluoroscopy and radiophotography examinations and an increase in CT and interventional examinations (Aroua et al. 2001)]. The total frequency of examinations excluding dental radiology is 760 examinations per 1,000 population per annum. This figure is lower than the corresponding UNSCEAR 2000 average of 920 for countries of high health quality level. Table 9 compares the result found in this work with those reported by other countries of similar health care level, and the figures vary within a factor of 3 between less than 500 in UK to almost 1,500 in Japan.

The annual collective dose totals 7,110 person.Sv, which amounts to 1.0 mSv per caput per annum. The UNSCEAR 2000 average for countries of high health level is 1.2 mSv per caput per annum including medical and dental radiology. The Swiss figure is higher than those reported by Denmark (0.36), Finland (0.45), United States (0.5), the Netherlands (0.6), and Sweden (0.68), comparable to those reported by Canada (0.94) and France (1.0), and lower than the German value (1.9) (UNSCEAR 2000).

This study shows that 43% of all the examinations, i.e., 581 per 1,000 population per annum, belong to dental radiology. The 1978 Swiss survey found a national mean of 464 dental examinations per 1,000 population per annum. This indicates an increase of about 25% in the use of dental radiology in Switzerland in 20 years. The present figure is higher than the average of 310 given in UNSCEAR 2000 (the actual values for countries can deviate strongly from this average). Table 9 compares the result found in this work with those reported by other countries of similar health care level, and the figures vary within a factor of 4.6 between less than 200 in the Netherlands and more than 800 in Japan. This study shows also that dental radiology contributes only 1% to the collective dose, i.e., 10 μSv per caput per annum,

Table 9. Annual frequencies of x-ray examinations per 1,000 population (UNSCEAR 2000).

Country	Medical	Dental	Radiography[a]	Radiography and Fluoroscopy[b]	Mammography	Angiography	Interventional	CT
Canada	934	–	747	60	79	7	0.31	41
Denmark	510	471	–	–	–	–	–	–
Finland	704	290	–	–	34	–	1.7	25
France	–	–	–	–	–	–	–	33
Germany	1,254	276	992	47	68	24	2.2	64
Italy	–	–	–	–	–	–	–	29
Japan	1,477	839	1,139	153	–	5.6	–	
Luxembourg	1,046	469	869	38	50	13	–	76
Netherlands	598	182	297	30	47	0.63	1.3	32
Norway	708	–	483	26	–	11	–	48
Sweden	568	739	362	28	80	8.1	3	39
United Kingdom	489	212	408	17	27	5.2	4.5	21
United States	962	–	–	–	–	–	–	91
Average[c]	920	310	710	66	25	7.6	3.0	57
Switzerland (this work)	760	581	641	17	31	9.9	3.8	46

[a] This category is not identical to the "Radiography" category considered in this work. It is based on UNSCEAR categorisation and covers chest, limbs and joints, spine, pelvis and hip, head and abdomen.
[b] This category is not identical to the "Radiography and Fluoroscopy" category considered in this work. It is based on UNSCEAR categorisation and covers GI tract, cholecystography, and urography.
[c] This average is calculated from rounded estimates based on self-consistent frequency data from a selected sample of representative countries (UNSCEAR 2000, Table 30 of Appendix C).

which is the same value given in UNSCEAR 2000 as average for countries of similar health care level.

Conventional radiographic examinations represent an important proportion of the total number. With a frequency of 642 examinations for 1,000 population per annum, they account for 48% of the total (84% if one excludes dental examinations). Table 9 compares the result of this study with those reported by other countries of similar health care level. The category "Radiography" used in this comparison corresponds to that proposed by UNSCEAR covering chest, limbs and joints, spine, pelvis and hip, head, and abdomen. The average is 710, but the individual country figures vary with a factor of 3.8 between less than 300 in the Netherlands and more than 1,100 in Japan. Conventional radiographic examinations contribute 41% to the collective dose.

With regard to CT examinations, they represent 3.4% of the total. This amounts to 46 examinations per 1,000 population per annum. For comparison, the corresponding figures given in UNSCEAR 2000 are an average value of 57 and individual country figures varying within a factor of 3.6 between 21 in UK and 76 in Luxembourg (see Table 9). CT examinations are found to contribute 28% to the collective dose.

The examinations involving radiography and fluoroscopy account for 1.6% of the total, i.e., 22 examinations per 1,000 population per annum. Table 9 presents a comparison for a category close to that considered in this work, covering the GI tract, cholecystography, and urography. The figure corresponding to this work (17 examinations per 1,000 population per annum) is to be compared to the average of 66 given for countries of similar health care level and the individual country figures varying from 17 in UK to 153 in Japan (almost one order of magnitude). Note that the number of examinations presented here does not include fluoroscopies performed in operating theatres, which are estimated at 150,000 per annum (Aroua et al. 2001). If they were to be included, the number of examinations involving radiography and fluoroscopy would be roughly doubled (34 examinations per 1,000 population per annum). Examinations involving radiography and fluoroscopy, excluding fluoroscopies performed in operating theatres, contribute 17% to the collective dose.

Angiography examinations account for 0.7% of the total, that is 9.9 examinations per 1,000 population each year. The average number given by UNSCEAR is 7.6 with country variations between 0.63 in the Netherlands and 24 in Germany (within a factor of 38) as shown in Table 9. Angiography examinations contribute 7.8% to the collective dose.

Interventional examinations account for 0.3% of the total, that is 3.8 examinations per 1000 population each year to be compared with the average for countries of similar health care level which equals 3.0 (see Table 9), the country to country variation being within a factor of 14 (from 0.31 in Canada to 4.5 in UK). Interventional examinations contribute 3.6% to the collective dose.

Mammography examinations account for 2.3% of the total, that is 31 examinations per 1,000 population each year. The UNSCEAR 2000 average for countries of similar health care level is 25, but the individual country figures can be as high as 80 in Sweden. Mammography

examinations contribute 0.6% to the collective dose, i.e., 6 μSv per caput per annum.

Bone densitometric examinations amount to 0.3% of the total, with 5 examinations per 1,000 population annually, and give less than 6 millionths of the collective dose, i.e., about 6 nSv per caput annually.

Finally, conventional tomographic examinations represent only 0.1% of the total, that is 2 examinations per 1,000 population per annum and 0.7% in the collective dose, amounting to 7 μSv per caput per annum.

If one now looks at the collective dose according to establishment categories, Table 2 shows that large hospitals contribute 10% of the total number of examinations N and more than 26% to the collective dose E_{col}. Small hospitals make up 21% of N and more than 46% of E_{col}. Private institutes of radiology share 2.6% in N and close to 7% in E_{col}. General practitioners contribute close to 16% to N and 9.4% to E_{col} while the dentists give 42% part of N but only 1% of E_{col}. The contribution of the chiropractors amounts to 0.6% in N and 2% in E_{col}. As regards other establishments, they make up 7.4% of N and 8.1% of E_{col}.

Table 2 shows also the average annual number of examinations per establishment, which varies from 373 for GP to 85,782 for large hospitals. The categories "small hospitals" and "large hospitals" are rather broad and were used in this study to distinguish between those who provided detailed information on the examinations performed during the period of the survey and those who gave yearly statistics only. The average annual number of examinations per hospital was therefore calculated for more realistic and specific types of hospitals according to the Swiss categorization. This number was found to be 3,788 for a district hospital, 5,457 for a private hospital, 11,512 for a regional hospital, 20,505 for a city hospital, 29,582 for a cantonal hospital, and 109,862 for a university hospital.

Radiologists practice both in private institutes of radiology and in radiology departments of small and large hospitals. All the data collected in small hospitals are considered to be provided by radiology departments. For large hospitals, the contribution of radiology departments is estimated to be 90% of the total number of examinations and 60% of the collective dose. In fact, although cardiology, gastro-enterology, and urology departments perform 10% of the examinations only in large hospitals, the fact that they are often concerned with dose-intensive examinations results in a 40% contribution of these departments to the collective dose. The part of radiologists in the usage of diagnostic and interventional radiology is therefore estimated to 33% in terms of total number of examinations and 71% in terms of collective dose.

The influence of the high numbers of dental and thorax radiographies leads to the result that 49% of all the examinations cover the head and neck region and 20% the thoracic region (Table 3). The upper and lower limbs share 19% of the total, whereas the abdomen and pelvis regions represent 4% and 8%, respectively.

Fig. 2 indicates that the age profile of the population of patients is quite different from that of the general population. The shift of the age distribution of the population of patients is estimated to about 15 y towards higher ages, the maximum of the age distribution of patients, all examination types considered, being between 60 and 70 y. The ratio of effective dose corrected and non corrected for the age effect according to the three models considered (Table 4) reflects the age limits of each model. Table 5 shows that the mean ratio varies from one model to another between 0.57 and 0.62 with a mean value of 0.60. When the different categories of examinations are compared, one can see how the ratio decreases when the maximum of the age distribution increases. At the extremes, the ratio has a mean value of 0.90 for dental radiology where we have a high component of children and a mean value of 0.45 for interventional radiology where the patients are almost exclusively old persons.

When excluding the dentists from the analysis, the overall results (Table 6) show that 29% of the examinations are performed on patients as a result of an accident, 64% on patients showing an illness, and 7% for other reasons (e.g., screening). The distribution of the answers varies widely depending on the medical specialty. For the hand surgeons 49% of the examinations concern patients who had an accident, but this type of patient represents less than 1% of the examinations performed by urologists. Inversely, the examinations on illness-patients represent 67% for ENT specialists, 62% for general practitioners, and 45% for paediatricians.

As shown in Table 7, about 62% of the examinations are believed by the physician to be necessary for diagnostic purposes or to institute or adjust a treatment (answers 4–6). Twenty-two percent of the examinations concern patients without a recognized health problem, but for whom the examination can provide a potential benefit, e.g., the screening of an illness at an asymptomatic stage (answers 1–3).

One sees in Table 8 that a considerable fraction of the examinations are performed on healthy patients.

CONCLUSION

This survey provided valuable data on the situation of diagnostic and interventional radiology in Switzerland for the year 1998. The results indicate that around 9.5

million radiodiagnostic examinations are performed each year in Switzerland, i.e., 1.34 examination per caput, and that the associated annual collective dose is of the order of 7100 person.Sv, which corresponds to an average annual effective dose per caput of 1.0 mSv.

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

The present survey did not deal with a number of issues that deserve the research attention of future work: a) *Survey of operating theatres:* a survey of the population (or a sample) of hospitals with operating theatres would provide valuable data about the annual number of fluoroscopies and their duration by type of intervention. This would enable an accurate evaluation of their associated collective dose; and b) *Dose distribution among the population:* this survey did evaluate the average effective dose to the population due to diagnostic and interventional radiology. But the surveyed data cannot yield the distribution of the dose among the population nor can it circumscribe the part of the population which receives the largest doses (people who undergo a large number of examinations). A patient-oriented survey on a stratified sample of the population would do that, in addition to shedding more light on the radiological impact.

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

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

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

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

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

The knowledge of the doses involved and the availability of guiding or reference values against which one can make comparisons are essential for all the examinations. Furthermore, it would be useful to establish a national dosimetric database for collecting all the measured doses to patients in Switzerland. Clearly medical physicists would have a central role to play in such a program. The database thus constructed and continuously updated should be made available to all institutions and individuals interested.

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

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

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