EXPOSURE OF THE SWISS POPULATION BY MEDICAL X-RAYS: 2008 REVIEW

Eleni Theano Samara,* Abbas Aroua,* François O. Bochud,* Barbara Ott,[†] Thomas Theiler,[†] Reto Treier,[†] Philipp R. Trueb,[†] John-Paul Vader,[§] and Francis R. Verdun*

Abstract—**Nationwide surveys on radiation dose to the population from medical radiology are recommended in order to follow the trends in population exposure and ensure radiation protection. The last survey in Switzerland was conducted in 1998, and the annual effective dose from medical radiology was estimated to be 1 mSv y^{-1} per capita. The purpose of this work was to follow the trends in diagnostic radiology between 1998 and 2008 in Switzerland and determine the contribution of different modalities and types of examinations to the collective effective dose from medical x-rays. For this reason, an online database (www.raddose.ch) was developed. All healthcare providers who hold a license to run an x-ray unit in the country were invited to participate in the survey. More than 225 examinations, covering eight radiological modalities, were included in the survey. The average effective dose for each examination was reassessed. Data from about 3,500 users were collected (42% response rate). The survey showed that the annual effective dose was 1.2 mSv/capita in 2008. The most frequent examinations are conventional and dental radiographies (88%). The contribution of computed tomography was only 6% in terms of examination frequency but 68% in terms of effective dose. The comparison with other countries showed that the effective dose per capita in Switzerland was in the same range as in other countries with similar healthcare systems, although the annual number of examinations performed in Switzerland was higher.**
Health Phys. 102(3):263–270; 2012

Key words: dose, population; medical radiation; surveys; x rays

INTRODUCTION

MEDICAL EXPOSURE to x-rays represents the major source of man-made irradiation of the population. At the world level, the annual per capita effective dose is about 3.1 mSv (UNSCEAR 2010). Although diagnostic radiology represents only 20% of the effective dose, it accounts for more than 94% of the man-made component. Similarly, in Switzerland the annual per capita effective dose amounted to 4 mSv in 2009 (FOPH 2010). Diagnostic radiology represented 30% of the total but more than 92% of man-made irradiation.

Surveys on population exposure by medical x-rays are recommended as a useful tool in radiation surveillance and protection at both the national and international levels (Swiss Federal Act 2004; UNSCEAR 2010). According to the European Commission (EC 2008a and b), the situation should be reassessed ideally every 5 to 10 y due to the pace of technological developments in the field of radiology and the evolution of medical practice. At the international level, surveys on the exposure of the world population by medical radiology are conducted every decade by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

Recently, several countries conducted nationwide surveys, including Finland[†] (2008 data), France (Etard et al. 2010) (2007 data), Germany (Bernhard-Ströl et al. 2010) (2008 data), the Netherlands (De Waard and Stoop 2010) (2008 data), Norway[‡] (2008 data), the United Kingdom (HPA 2010) (2008 data), and the United States of America (NCRP 2009) (2006 data).

Switzerland has surveyed the exposure of the population by medical x-rays since the late 1950s. The last full reevaluation survey concerned the 1998 data (Aroua et al. 2002a and b). It provided detailed information on the frequency of the x-ray examinations performed in Switzerland and the associated radiation doses. The annual dose per capita was estimated to be 1.0 mSv. The last updating survey concerned the 2003 data (Aroua et al. 2007a) and revealed that the use of computed tomography (CT) had registered a significant increase (70%) in a 5-y period, which led to an increase of the dose to 1.2 mSv.

*Institute of Radiation Physics, Lausanne University Hospital, Rue du Grand-Pré 1, CH-1007, Lausanne, Switzerland; [†]Radiation Protection Division, Federal Office of Public Health, CH-3003, Bern, Switzerland; [§]Institute of Social and Preventive Medicine, Lausanne University Hospital, Rte de la Corniche 2, CH-1066, Epalinges, Switzerland.

Funding received from the Swiss Federal Office of Public Health and the Swiss National Science Foundation.

For correspondence contact: Eleni-Theano Samara, Rue due Grand-Pre 1, 1007, Lausanne, Switzerland, or email at eleni-theano.samara@chuv.ch.

(*Manuscript accepted* 29 *August* 2011)
0017-9078/12/0

DOI: 10.1097/HP.0b013e31823513ff

[†]Personal communication, H. Järvinen, Finnish Radiation and Nuclear Safety Authority (STUK), Laippatie 4, P.O. Box 14, 00881 Helsinki, Finland, 17 May 2011.
[‡]Personal communication, H. Olerud, Norwegian Radiation Protection Authority, P.O. Box 55, N-1332, Østerås, Norway, 17 May 2011.

The aim of this work was to reassess the exposure of the Swiss population to medical x-rays in 2008 by updating the associated annual frequency of examinations, the effective doses per examination, and the annual collective effective dose and to compare Switzerland in terms of collective effective dose with other countries with similar healthcare systems.

MATERIALS AND METHODS

During the 2008 survey, all healthcare providers in the country authorized to operate an x-ray unit were contacted and invited to participate. This amounted to 8,247 practices, radiology institutes, and hospital departments, running 17,391 x-ray units of all kinds authorized by the Regulatory Authority (Federal Office of Public Health, FOPH).

To increase the probability of participation, several options were offered to the participants on how to provide their frequency data: paper form by post mail, electronic form by email, or online registration. For this last option, a dedicated website and database (www.raddose.ch) were developed.

The participants were encouraged to complete a form with reference categories of examinations based on the European Guidance No. 154 (EC 2008a): 225 examinations grouped into eight radiological modalities (radiography, conventional fluoroscopy, diagnostic interventional radiology, therapeutic interventional radiology, computed tomography, dental radiology, mammography, and bone densitometry). According to the Guidance, "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." In case the participant was not able to provide data concerning the 225 examinations, he/she could use 70 broader categories. The participants were also allowed to provide data in the format of their choice: local categories or medical tariff codes (Tarmed). The list of the examinations can be found at the website www.raddose.ch.

After 10 mo and three reminders, the frequency data collection was closed. Data processing included importing data into the database for the statistics received by email or in paper form, a data check for statistics registered online, and typing error correction where necessary. The data received in local categories or in Tarmed format were redistributed over the reference categories. The distribution of the examinations varied among different healthcare providers (medical practices, dental practices, chiropractors, hospital departments, and radiology institutes). The data entry and analysis were performed by an experienced radiographer and a medical physicist.

National frequencies were established by projecting the collected statistics according to the number of installations in the survey, according to the following formula:

$$N_{2008} = \sum_{i,j} \frac{I_{total}(i,j)}{I_{part}(i,j)} \times N_{part}(i,j), \qquad (1)$$

where N_{2008} is the national examination frequency, i is the type of healthcare provider (medical practices, dental practices, chiropractors, hospital departments, and radiology institutes), j is the type of x-ray unit, I_{total} is the number of x-ray installations in Switzerland, I_{part} is the number of x-ray installations run by healthcare providers that participated in the survey, and N_{part} is the number of examinations performed by the healthcare providers who participated in the survey.

A sensitivity analysis was performed in order to assess the effect on the result if the non-participants had features that were different from those of the participants, in particular the frequencies of examinations performed. The hypothesis was made that the non-participants perform 20% more or 20% fewer examinations.

For radiography examinations, the technical parameters were reassessed, and the effective dose was calculated using the 2008 version of the software program PCXMC (PCXMC version 2.0, 2008, STUK, Laippatie 4, P.O. Box 14, 00881, Helsinki, Finland) (Tapiovaara et al. 1997). For CT examinations, the effective doses were reviewed in an auditing campaign (Treier et al. 2010; Deak et al. 2010). The effective doses for some fluoroscopic procedures were updated in the last couple of years by surveys in large and small hospitals (Aroua et al. 2007b; Samara et al. 2010, 2011). For other examinations, bibliographic data were used. The effective doses for all examinations as well as a description of the dosimetric method used for each radiological modality are provided in the national report (Aroua et al. 2011).

The tissue weighting factors provided by the International Commission on Radiological Protection in its Publication 60 (ICRP 1991) were used for the calculation of the effective dose.

RESULTS

In terms of number of healthcare providers, the overall response rate was 42% corresponding to 3,503 respondents. In terms of x-ray units, the overall response rate was 45%. Two-thirds of the participants registered their data online. Of the remaining one-third, half sent their data electronically and the other half in paper form. Table 1 shows the response rates for the three broad

Table 1. Response rates for the 2008 Swiss survey.

	Health care providers			X-ray units		
Category of healthcare providers	Total	Respondents	Rate (%)	Total	Respondents	Rate (%)
All categories	8,247	3,503	42	17,391	7,878	45
Medical	4,587	1,953	43	6,714	3,376	50
Dental	3,526	1,461	41	10,553	4,418	42
Chiropractic	134	89	66	124	89	66
Radiology institutes	85	39	46	347	170	49
Hospital departments (all)	383	249	65	2,394	1,519	63
in university hospitals	53	26	49	543	242	45
in canton hospitals	62	40	65	481	354	74
in district hospitals	111	80	72	685	446	65
in state hospitals	14	10	71	94	67	71
in private hospitals	132	87	66	576	403	70
in houses for the elderly	11	6	55	15	7	47

categories of health care providers (medical, dental, and chiropractic) as well as for radiology institutes and various types of hospital departments. The sample of participants was also investigated with regard to the geographical distribution in the country (Fig. 1). The range of regional variation was found to be between 41–46% for all the categories of healthcare providers (Aroua et al. 2011).

Under the hypothesis that the non-participants performed 20% more or 20% fewer examinations than the participants, a mean difference of about 9% with respect to the national examination frequencies was obtained. The difference was smaller for interventional radiology ([minus]4%, +4%) and bigger for dental radiology ([minus]12%, +12%). For dental radiology, the number

Fig. 1. The seven regions of Switzerland according to the Swiss Federal Office of Statistics.

Table 2. 2008 Swiss annual frequency and dose data.

Radiological modality	Number of examinations (in thousands)	Collective dose (person-Sv)	Number of examinations/ 1,000 population	Effective dose per capita (mSv)
Radiography	6,000	1,330	780	0.17
Conventional fluoroscopy	153	415	20	0.05
Interventional — diagnostic	56	553	7.2	0.07
Interventional — therapeutic	46	528	6.0	0.07
Computed tomography	780	6,150	100	0.8
Dental radiology	5,430	63	700	0.01
Mammography	387	62	50	0.01
Bone densitometry	117	0. 31	15	0.00004
Total	13,000	9,100	1,700	1.2

of non-participants was higher than that of participants (Aroua et al. 2011).

Table 2 shows the annual number of examinations performed in Switzerland in 2008, the number of examinations per 1,000 population, as well as the associated collective dose and the average per capita effective dose delivered by all medical radiodiagnostics together and by each individual radiological modality. This study revealed that the total number of x-ray examinations carried out in Switzerland was 13 million per year in 2008, corresponding to 1.7 examinations per capita. The associated collective effective dose accounted for 9,100 person-Sv, which, as reported to the Swiss population (7.7 million), resulted in an average effective dose of 1.2 mSv per capita.

Fig. 2 presents the distribution of the total annual number of examinations and the collective dose over the eight radiological modalities. Although the highest contributions to the total number of examinations came from radiography (46%) and dental radiology (42%), in terms of collective effective dose, the contribution of radiography was only 14.6% and that of dental radiology less than 1%. In contrast, computed tomography contributed only 6%

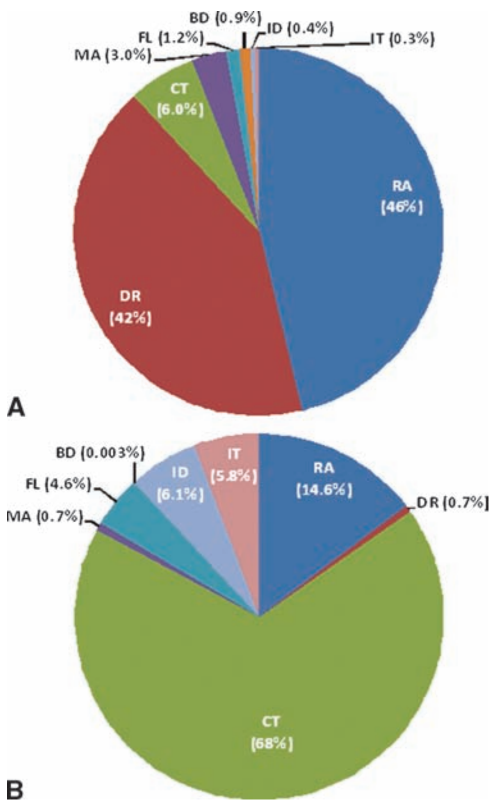

Fig. 2. Distribution of the total annual number of examinations (A) and the total annual collective dose (B) over the various radiological modalities: radiography (RA), conventional fluoroscopy (FL), diagnostic interventional radiology (ID), therapeutic interventional radiology (IT), computed tomography (CT), dental radiology (DR), mammography (MA), bone densitometry (BD).

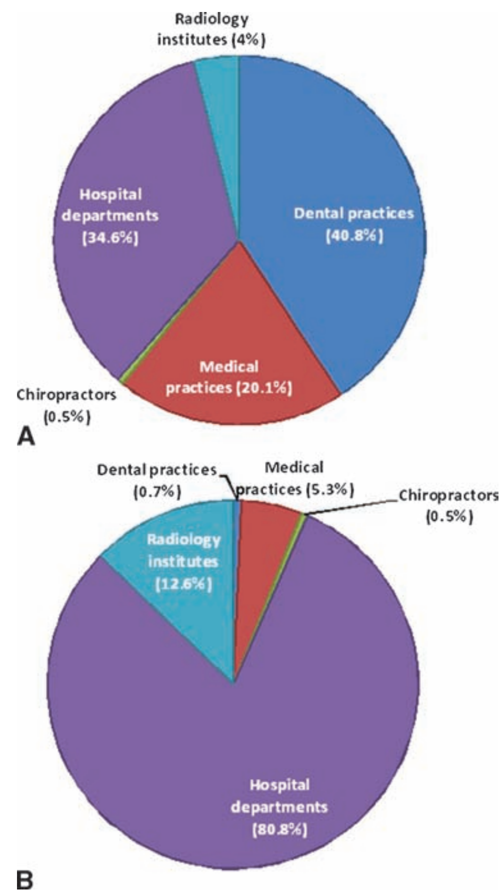

Fig. 3. Frequency (A) and collective dose (B) contribution of the different healthcare providers.

Table 3. Frequency and dose for the most frequent examinations.

Modality	Most frequent examination	Number of examinations/ 1,000 population 1998	Effective dose 1998 (mSv)	Number of examinations/ 1,000 population 2008	Effective dose 2008 (mSv)
Radiography	Chest radiography	2.10×10^{2}	5.74×10^{-2}	$2.27 \times 10^{+2}$	5.05×10^{-2} (ICRP 60) 5.40×10^{-2} (ICRP 103)
Fluoroscopy	Shoulder arthrography	1.15×10^{0}	1.30×10^{-1}	5.30×10^{0}	1.30×10^{-1} (ICRP 60)
Diagnostic interventional radiology	Cardiac angiography	2.71×10^{0}	9.24×10^{0}	4.44×10^{0}	1.12×10^{1} (ICRP 60)
Therapeutic interventional radiology	Percutaneous cardiac intervention	1.37×10^{0}	1.08×10^{1}	2.37×10^{0}	1.70×10^{1} (ICRP 60)
CT	CT full abdomen	9.45×10^{0}	1.04×10^{1}	1.97×10^{1}	1.17×10^{1} (ICRP 60)
Mammography	Mammography	2.96×10^{1}	2.00×10^{-1}	3.69×10^{1}	1.60×10^{-1} (ICRP 60)
Dental radiology	Periapical	2.84×10^{2}	5.41×10^{-2}	3.26×10^{2}	5.00×10^{-3} (ICRP 60)
Bone densitometry	Lumbar spine	2.55×10^{0}	1.46×10^{-3}	5.69×10^{0}	4.00×10^{-3} (ICRP 60) 4.00×10^{-3} (ICRP 103)

to the number of examinations but made up more than two-thirds of the collective effective dose. Likewise, interventional radiology (diagnostic and therapeutic), whose contribution in terms of frequency of examinations was only 0.8%, delivers nearly 12% of the collective effective dose.

Fig. 3 shows the frequency and dose contribution of the different healthcare providers. Hospitals undertook 34.6% of the examinations, which resulted in 81% of the collective dose. Radiology institutes contributed 4% in terms of frequency and 12.6% in terms of the collective dose. Dental practices performed almost 41% of the examinations but were responsible for only 0.7% of the collective dose. Medical practices performed a fifth of the examinations and contributed 5.3% to the collective dose. Chiropractors performed 0.5% of the frequencies and 0.5% of the collective dose.

Table 3 shows the number of examinations per 1,000 population as well as the effective dose for the most frequent examinations of each radiological modality performed in Switzerland in 2008. In the table, the corresponding frequencies and effective doses used in the 1998 survey are also presented. For all the examinations, an increase in the frequencies was observed, for instance 70% for cardiac interventional procedures. The numbers of CT full abdomen examinations and bone densitometry examinations of the lumbar spine have doubled over the decade. The effective doses were estimated using the ICRP 60 recommendations for all the examinations and are presented in the last column of the table. Comparing the effective doses used in the 1998 and 2008 survey, one may observe that the revised doses may differ significantly; for example, the effective dose for percutaneous coronary intervention, which in 1998 was estimated to be 10.8 mSv and 17 mSv in 2008. For radiography examinations, the estimation of the effective dose was also performed using the ICRP 103 recommendations. In Table 3, one may remark that the difference using the ICRP 60 and 103 was only 7% for chest radiography.

DISCUSSION

During the 1998 survey, a sample of 3,000 establishments was contacted and 1,800 participated, resulting in a response rate of 60% (Aroua et al. 2002a). In the present survey, national examination frequencies were estimated by contacting all healthcare providers in the country. The

Table 4. 2008/1998 ratios of the frequency and dose in Switzerland.

Radiological modality	Number of examinations	Collective dose	Number of examinations/ 1,000 population	Effective dose per capita
Radiography	1.32	0.45	1.21	0.42
Conventional fluoroscopy	0.98	0.34	0.90	0.31
Interventional — diagnostic	0.79	1.00	0.73	0.93
Interventional — therapeutic	1.72	2.06	1.59	1.90
Computed tomography	2.38	3.11	2.19	2.86
Dental radiology	1.32	0.87	1.21	0.80
Mammography	1.73	1.43	1.60	1.32
Bone densitometry	3.64	7.55	3.36	6.96
Total	1.36	1.30	1.26	1.20

response rate in the 2008 survey was lower than in 1998 (42%), but this corresponded to 3,486 respondents, which is almost twice the number of respondents in 1998.

Table 4 compares the frequency and dose data obtained in the present study with the data established in Switzerland in 1998. The first two columns of the table present the ratio of examination frequency and collective dose between 2008 and 1998 (absolute values) and the last two columns the ratio of the number of examinations per 1,000 population and the average effective dose per capita. Some of the increase in the absolute values may be associated with the increase in the Swiss population (8.5% in a decade). Thus, to eliminate the demographic factor, the examination frequencies per 1,000 population and the effective doses per capita were compared. The number of conventional fluoroscopy and diagnostic interventional procedures showed a decrease of 10% and 30%, respectively, in terms of number of examinations. Inversely, the number of therapeutic intervention procedures showed an increase of 60% in a decade corresponding to an increase in effective dose per capita of 90%. This can be explained by the fact that cases previously treated with open surgery may now be safely and effectively treated by interventional procedures (Balter et al. 2008). Accordingly, the increase in the dose delivered by this kind of procedure may be attributed to the fact that more complex cases may now be treated interventionally, resulting, however, in higher patient doses (Balter et al. 2008). The main increase in the collective dose in a decade may be attributed to the increase in computed tomography (286% in terms of collective dose since 1998, Table 4). The increase in the number of CT examinations had already been observed (Aroua et al. 2007a) and attributed to the introduction of multi-slice CT scanners. This technology advance led, in turn, to a change in medical practice by replacing fluoroscopy-guided procedures with CT scans. This may also explain the reduction in the number of diagnostic interventional procedures. It is important to note here that for this survey, no CT scans associated to SPECT/CT examinations, PET/CT examinations or for radiation therapy planning were taken into account. The number of bone densitometry examinations has notably increased (3.36 times) since 1998, as seen in Table 4; however, its associated dose was too low to affect the collective effective dose significantly (Table 2). Some increase in these examinations may be attributed to the population aging and thus the diagnosis of osteoporosis as well as the follow-up of osteoporosis treatments.

The first survey in radiodiagnostics in Switzerland was conducted in 1957 by Zuppinger (Zuppinger et al. 1961). The survey determined the number of radiological examinations and estimated the genetically significant dose (GSD) at 22.3 mR. The second survey was carried out in 1971, and the GSD was found to have doubled to 42.9 mR (Poretti et al. 1971). Another survey was performed in 1978, and the GSD was found to be 25.6 mR (Mini and Poretti 1984). In the latter survey, the average dose to the bone marrow (to measure the risk of leukemia due to radiation exposure) was estimated at 0.63 mSv. The survey performed in 1989–1990 by Mini (1992) focused on the dose estimation for different radiological modalities and provided a lot of information on patient radiation protection. However, no estimation of population dose was performed. The 1998 survey determined the radiation doses and frequencies of examinations. The annual dose was estimated to be 1.0 mSv per capita (Aroua et al. 2002a). Five years later, a small survey was performed in order to follow the trends in diagnostic radiology and revealed that the annual dose was increased to 1.2 mSv per capita, mainly due to the increase in the number of CT examinations. In the current survey, average effective doses of all examinations were reassessed, and the collective effective dose was found to be 1.2 mSv y^{-1} per capita (Aroua et al. 2007a). Therefore, no change was observed, although the frequency increased during this 5-y period. This is explained by the change of the dose vectors. The updated effective doses per examination for radiographies are significantly lower than previous values (Aroua et al. 2011). If the dose vector established in 1998 were used with the 2008 frequency data, the average effective dose would amount to 1.4 mSv per capita.

The first surveys dealt with radiographies and fluoroscopy examinations. All surveys since 1998 covered all eight radiological modalities (CT, mammography, bone densitometry, etc). In 1957, the annual number of examinations per capita was estimated to be 0.97 (Zuppinger et al. 1961), while the 1971 survey showed that the number increased to 1.35 (Poretti et al. 1971) and remained stable according to the 1978 survey (Mini and Poretti 1984). The 1998 survey showed that the annual number of examinations per capita was 1.3 (Aroua et al. 2002a). In 2003, the

Table 5. Frequency and dose comparisons with data reported in other countries.

Country	Number of x-ray examinations /1,000 population	Annual per capita effective dose due to x-rays (mSv)
UNSCEAR — Health level I (1997–2007)	1,607	1.9
Finland (2008)	717	0.45
France (2007)	1,152	1.2
Germany (2008)	1,650	1.7
Netherlands (2008)	573	0.7
Norway (2008)[a]	670	1.1
United Kingdom (2008)	752	0.4
USA (2006)	1,257	2.2
Switzerland (2008)	1,700	1.2

[a]Excluding dental.

annual number of examinations was shown to have increased to 1.5 (Aroua et al. 2007a), while this survey showed a further increase to 1.7 examinations per capita.

Table 5 compares the frequency and dose data obtained in the present study with the data reported recently by seven countries: Finland, France, Germany, the Netherlands, Norway, the UK and the U.S. The data presented in the 2008 UNSCEAR report for countries with similar healthcare systems to Switzerland (level I), which covers the decade 1997–2007, is also included for comparison. For the Netherlands, France, and the U.S., nuclear medicine was included in the reported figures and had to be removed for the comparison of the x-ray component. The annual number of examinations per 1,000 population established in this work (1,700) is the highest among the countries of interest. This is due to the high frequency of dental x-ray examinations in Switzerland. The average annual per capita effective dose of 1.2 mSv compares well with the figures reported in other countries, ranging from 0.4 mSv in the UK to 2.2 mSv in the U.S.

This survey has its limitations. First, the participation of the x-ray users was 42% and, thus, the frequencies of the examinations had to be projected to cover the whole population. However, as it was decided to contact all the users in the country to estimate the examination frequencies, and the respondents were verified as being a representative sample of the entire country, the authors feel confident of the accuracy of the results obtained. Second, the effective dose estimation was based on the ICRP 60 recommendations. Dose calculations were performed with both ICRP 60 and 103 weighting factors mainly for CT and radiography examinations as they contribute the most to the collective dose. For other modalities, bibliographic data were used and, at the time the survey was performed, limited works considered effective dose calculations using the ICRP 103 recommendations. However, the changing of the weighting factors according to the recommendations of ICRP 103 does not play an important role as it was recently shown (Hart et al. 2010).

The 2008 survey allowed estimation of the annual population dose in Switzerland following the trends in x-ray diagnostic and interventional radiology. The most challenging part of the survey was frequency data collection. However, at the end of the survey, a representative sample of the respondents was obtained. The projection method to estimate the annual examinations in the whole country used in the 2008 survey was based on the number of x-ray units run by the healthcare providers. Unlike the 1998 survey where the number of practices and hospital departments was used to project the data associated with the participating sample to the total number in the country, in the present investigation the total number of x-ray units was available, and the authors chose to use it since it leads to more accurate results. These results showed a significant increase in the number of CT examinations and bone densitometry examinations as well as an increase in the number of interventional procedures. Thus, more efforts should be made on radiation protection for these modalities.

CONCLUSION

This work updated the frequency and collective dose data for medical and dental examinations in Switzerland for 2008. The survey showed that Switzerland stands at the same level as other countries with similar healthcare systems in terms of effective dose per capita. However, the annual number of examinations per capita in Switzerland was higher than that performed in other countries due to the high number of dental examinations performed in the country. The main contributor to the collective effective dose was computed tomography. It is important to perform surveys regularly in order to follow the trends in population exposure and identify clearly the points to focus on for future optimization campaigns.

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