Exposure of the Swiss population by Medical X-rays: 2008 Review

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June 2011

Light Version without Appendices

This research project was jointly funded by the Swiss Federal Office of Public Health (contract Nr. 08.004670/434.0000/-53) and the Swiss National Science Foundation (subsidy Nr. 32003B_127461).

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 then estimated to be 1 mSv/caput. The purpose of this work was to follow the trends in diagnostic and interventional radiology between 1998 and 2008 in Switzerland and determine the contribution of the different modalities and types of examinations to the collective effective dose from medical X-rays. An online database (www.raddose.ch) was developed to this effect, and 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 considered and the average effective dose for each examination was reassessed. Data from about 3500 users were collected (42% response rate). The survey showed that the average frequency of X-ray examinations was 1.7 per caput and the average annual effective dose due to medical X-rays was 1.2 mSv/caput in 2008. The most frequent examinations were conventional and dental radiographies (88%). The contribution of computed tomography was only 6% in terms of examination frequency but as high as 68% in terms of the collective effective dose. The comparison with other countries showed that the collective effective dose 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.

Keywords

Diagnostic, interventional, radiology, medical radiation, X-rays, dose, population, survey

Zusammenfassung

Um die Entwicklung der öffentlichen Strahlenbelastung durch medizinische Radiologie zu verfolgen und einen entsprechenden Strahlenschutz gewährleisten zu können wird empfohlen landesweite Erhebungen zur Strahlendosis durch solche medizinischen Untersuchungen durchzuführen. Die letzte Erhebung in der Schweiz wurde 1998 durchgeführt, woraufhin die jährliche effektive Strahlendosis durch medizinische Radiologie auf 1 mSv pro Einwohner geschätzt wurde. Ziel dieser Arbeit ist Veränderungen der Strahlenbelastung durch diagnostische und interventionelle Radiologie zwischen 1998 und 2008 in der Schweiz zu untersuchen und den Beitrag von verschiedenen Methoden der medizinischen Röntgenuntersuchung zur gesamten effektiven Strahlendosis zu bestimmen. Für diesen Zweck wurde eine Online-Datenbank entwickelt (www.raddose.ch). Alle Gesundheitsversorger die über eine Lizenz für den Betrieb einer Röntgenanlage verfügen wurden gebeten, an der Erfassung teilzunehmen. Es wurden mehr als 225 Untersuchungen einbezogen, die 8 verschiedene radiologische Methoden abdecken. Hiermit wurde die mittlere effektive Dosis für eine Untersuchung neu bewertet. Insgesamt wurden Daten von 3500 Benutzern gesammelt, was einer Antwortquote von 42% entspricht. Die Erhebung zeigt, dass sich im Jahr 2008 im Mittel jeder Einwohner 1.7 Röntgenuntersuchung unterzogen hat und, dass die mittlere effektive Dosis in diesem Jahr 1.2 mSv pro Einwohner betrug. Die häufigsten Anwendungen (88%) waren konventionelle und zahnmedizinische Radiographie. Der Anteil der Computertomographie betrug bezüglich der Häufigkeit der Anwendung 6%, bezüglich der kollektiven effektiven Dosis aber 68%. Der Vergleich mit anderen Ländern zeigt, dass sich die kollektive effektive Strahlendosis in der Schweiz im selben Bereich wie die in Ländern mit ähnlichen Gesundheitssystemen befand. Die jährliche Zahl von Untersuchung war in der Schweiz jedoch höher.

Résumé

Les enquêtes nationales visant à déterminer les doses de radiation délivrées à la population par la radiologie médicale sont recommandées afin de suivre les tendances de l'exposition de la population et assurer protection radiologique. La dernière enquête de ce genre a été menée en Suisse en 1998 et la dose efficace annuelle due à la radiologie médicale a été estimée à 1 mSv par habitant. Le but de ce travail était de suivre les tendances de la radiologie diagnostique et interventionnelle en Suisse, entre 1998 et 2008, et de déterminer la contribution des différentes modalités radiologiques et des divers types d'examens à la dose efficace collective due à l'application médicale des rayons X. Une base de données en ligne (www.raddose.ch) a été développée à cet effet, et tous les prestataires de soins détenant une autorisation à utiliser une installation radiologique dans le pays ont été invités à participer à l'enquête. Plus de 225 examens, couvrant huit modalités radiologiques, ont été considérés et la dose efficace moyenne pour chaque examen a été réévaluée. Les données concernant environ 3500 utilisateurs ont été recueillies, correspondant à un taux de réponse de 42%. L'enquête a montré qu'en 2008, la fréquence moyenne des examens radiodiagnostiques était de 1,7 par habitant et la dose efficace annuelle moyenne due aux rayons X médicaux était de 1,2 mSv par habitant. Les examens les plus fréquents étaient les radiographies conventionnelles et dentaires (88%). La contribution de la tomodensitométrie a été de 6% en termes de fréquence d'examens, et de 68% en termes de dose efficace collective. La comparaison avec d'autres pays a montré que la dose efficace moyenne par habitant en Suisse était dans la même gamme que celle enregistrée dans d'autres pays avec des systèmes de santé publique similaires, bien que le nombre annuel d'examens effectués en Suisse a été plus élevé à cause de la contribution élevé de la radiologie dentaire.

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Introduction

Medical exposure to X-rays represents a major source of man-made irradiation of the population. At the global level, the total annual per caput effective dose, due to all sources of irradiation, is about 3.1 mSv [UNSCEAR 2010]. Although diagnostic radiology represents only 20% of it, it accounts for more than 94% of the man-made component. Similarly, in Switzerland where the annual per caput effective dose amounted to 4 mSv in 2009 [FOPH 2010], diagnostic radiology represented 30% of the total, but more that 92% of man-made irradiation.

This is why both at national and international levels, surveying the population exposure by medical X-rays is recommended as a useful tool in radiation protection. While the Swiss Federal Act on Radiation Protection stipulates in Art. 5 that "the Confederation shall encourage scientific research on the effects of radiation and on radiation protection" [LRaP 2004], the European Commission states that the "Member States shall ensure that the distribution of individual dose estimates from medical exposure is determined for the population and for relevant reference groups of the population as may be deemed necessary by the Member State" [EU 1997]. Among the main objectives of population dose assessments are: "1) to observe trends in the annual collective dose and the annual average per caput dose from medical x-rays in a country with time; 2) to determine the contributions of different imaging modalities and types of examination to the total collective dose from all medical x-rays." [EC 2008a]

Because of the pace of technological developments in the field of radiology and the evolution of the medical practice, the situation is reassessed ideally every five years as recommended by the European Guidance on Estimating Population Doses from Medical X-Ray Procedures [EC 2008a, EC 2008b], or at least every ten years. At the international level, surveys on the exposure of the global population by medical radiology are conducted every decade by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). UNSCEAR has just issued its 2008 report [UNSCEAR 2010] with data covering the period 1997-2007.

Recently, several countries conducted nationwide surveys including Finland [Järvinen 2011] (2008 data), France [IRSN-IVS 2010] (2007 data), Germany [Bernhard-Ströl et al. 2010] (2008 data), the Netherlands [RIVM 2010] (2008 data), Norway [NRPA 2010] (2008 data), the United Kingdom [HPA 2010] (2008 data), and the United States of America [NCRP 2009] (2006 data).

Switzerland started surveying the exposure of the population by medical X-rays back in the late 1950s [Zuppinger et al. 1961, Poretti et al. 1971, Mini and Poretti 1984, Mini 1992]. The exposure of the Swiss population is reviewed periodically, every decade

with a full re-evaluation survey addressing all healthcare providers and every five years with an updating survey covering a small stratified sample of healthcare providers. The last full re-evaluation survey concerned the 1998 data [Aroua et al. 2002a, Aroua et al. 2002b]. It provided a significant amount of information on the frequency of the X-ray examinations performed in Switzerland and the associated radiation doses. The last updating survey concerned the 2003 data [Aroua et al. 2007a]. It revealed, for example, that the use of computed tomography (CT) had registered a sharp increase (70%) in a 5-year period.

The aim of the present work was to reassess the exposure of the Swiss population to medical X-rays in 2008 and to update the associated annual frequency of examinations, the effective doses per examination and the annual collective effective dose.

Methods

The survey was led by a steering group comprising representatives of Federal Office of Public Health (FOPH), the Institute of Radiation Physics (IRA) from the University Department of Radiology (DRM – CHUV, Lausanne) and the University Institute of Social and Preventive Medicine (IUMSP) from the University Department of Community Medicine and Health (DUMSC – CHUV, Lausanne). It was followed by a support group comprising representatives of most scientific and professional societies concerned: Association Romande de Radioprotection, College of General Practitioners, Federal Commission for Radiation Protection and Radioactivity Surveillance, Santésuisse, Swiss Society of Cantonal Chief-Physicians, Swiss Society of Cardiology, Swiss Society of Chiropractic, Swiss Society of Dental Medicine, Swiss Society of Gastroenterology, Swiss Society of General Medicine, Swiss Society of Internal Medicine, Swiss Society of Paediatrics, Swiss Society of Radiobiology and Medical Physics, Swiss Society of Radiographers, Swiss Society of Radiology, Swiss Society of Urology, and The Swiss Hospitals.

The recommendations of the European Group "Dose Datamed" on how to conduct national surveys on population exposure, which were accepted by the European Commission [EC 2008a], were followed in this survey.

During the 1998 nationwide survey all Swiss healthcare providers were addressed except general and dental medicine practices which were sampled at rates of 20% and 10% respectively. This time the whole community of healthcare providers possessing an authorisation to run an X-ray unit was addressed. This amounts to 8247 practices, radiology institutes and hospital departments (Table 1), running 17391 X-ray units of all kinds (Table 2) authorised by the Regulatory Authority which, in Switzerland, is the Federal Office of Public Health. The 8247 healthcare providers are distributed into 4587

medical, 3526 dental and 134 chiropractic. They cover 7779 practices (individual and group), 383 hospital departments and 85 radiology institutes.

Table 1: Healthcare providers performing X-rays in Switzerland

Category of healthcare provider	Number
Individual medical practices	3568
Group medical practices	529
University hospitals	53
Cantonal hospitals	62
District hospitals	111
City hospitals	14
Private hospitals	132
Homes for the elderly	11
Radiology institutes	85
Others	22
Total medical	4587
Individual chiropractic practices	125
Group chiropractic practices	9
Total chiropractic	134
Individual dental practices	3072
Group dental practices	284
Dental clinics	13
School dental radiology centres	124
Others	33
Total dental	3526
Grand total	8247

Table 2: Various types of X-rays units used in Switzerland

	Use of X-ray unit	Number
Total		17391
Generic	Dental	10553
	Medical	6704
	Chiropractic	134
Specific	Radiography	4937
	Radiography + Fluoroscopy	760
	Fluoroscopy (mobile)	476
	Interventional (intensive dose)	127
	Computed tomography	238
	Mammography	249
	Bone densitometry	147
	Small dental (< 70 kV)	8572
	Orthopantomography	1171
	Panoramic + teleradiography	661
	Teleradiography	4
	Dental volume tomography	49

In order to increase their probability of participation, the participants were offered several options on how to provide their frequency data: paper form by post mail, electronic form by email or by registration online. For this purpose, a dedicated website (raddose.ch) was developed beforehand (see Appendix 1). In the first letter sent to them, the participants received their own username and password to access their form.

The participants were encouraged to fill in a form with reference categories of examinations, based on the "Dose Datamed" methodology [EC 2008a]. This consists in 225 examination types grouped in seven radiological modalities: radiography, conventional fluoroscopy, diagnostic interventional radiology, therapeutic interventional radiology, computed tomography, dental radiology, mammography, and bone densitometry. In the case the participant was not able to provide data concerning the 225 examination types, he/she could use 70 broader categories (see Appendix 2). The participants were also allowed to send their data in the format of their choice: local categories or medical tariff codes (Tarmed).

After ten months and three reminders the frequency data collection was closed and the data processing started: introducing in the database the statistics received by email or in paper form, checking the data registered online and correcting the typing errors where necessary. The data received in local categories or in Tarmed format were redistributed over the reference categories.

National frequencies were established by projecting the collected statistics according to the number of X-ray units in the survey, with the following formula:

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

where N_{2008} is the national examination frequency, i refers to the healthcare provider (medical practice, dental practice, chiropractor, hospital department, radiology institute), j refers to the type of X-ray unit, I_{total} being the number of X-ray units in Switzerland, I_{part} the number of X-ray units run by healthcare providers who participated in the survey, and N_{part} the number of the examinations performed by the healthcare providers who participated in the survey.

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 number of X-ray units was available and we chose to use it since it leads to more accurate results. The difference in the frequency of examinations obtained by the two approaches was explored.

In the 1998 survey the effective doses related to the various types of examinations were calculated using dosimetric models specific to each radiological modality [Aroua et al. 2002b]. The effective doses were updated the last couple of years by surveying some fluoroscopic procedures in large and small hospitals [Aroua et al. 2007b, Samara et al. 2010, Samara et al. 2011]. For radiography examinations, the technical parameters were reassessed and the effective doses were calculated using the software program PCXMC [Tapiovaara et al. 1997] (See Appendix 3). The 2008 version of PCXMC was adopted (12, PCXMC version 2.0, 2008, STUK, Helsinki, Finland). For CT examinations, the effective doses were reviewed in an auditing campaign [Treier et al. 2010] (See Appendix 3). For some other examinations, bibliographic data were used [Brambilla et al. 2004, Chamberlain et al. 2000, Crawley and Rogers 2000, Crawley 2004, Danforth and Clark 2000, Delichas et al. 2004, Gibbs 2000, Gijbels et al. 2004, Gijbels et al. 2005, Hatziioannou et al. 2000, Karthikesalingam et al. 2009, Ludlow et al. 2008, Martin 2008, Mettler et al. 2008, Pantos et al. 2009, Perisinakis et al. 2003, Perisinakis et al. 2004, Ruiz Cruces et al. 1998, Smith et al. 2009, Şorop et al. 2008, Thomas et al. 2006, Tsalafoutas et al. 2005, Yakoumakis et al. 2001].

In the calculation of the updated effective doses the tissue weighting factors (w_T) given by the International Commission on Radiological Protection in its Publication 60 [ICRP 1991] were used. A couple of years ago the ICRP published new values in Publication 103 [ICRP 2007] as shown in Table 3.

The main changes are a decrease of the w_T of the gonads by a factor 0.4 and an increase of that of the breast by a factor 2.4. The two sets of w_T were compared for two radiological modalities. In the case of radiography the new figures lead to a 14% decrease in the collective dose, whereas in the case of CT a 2% increase is registered (see Appendix 4). In the most recent investigation performed in the UK [HPA 2010] a 2-3% decrease in the collective dose was registered for conventional radiology including dental and for CT and a 12-13% increase for interventional radiology. This was reflected in an overall 2% increase of the total collective dose due the w_T change.

Table 3: Tissue weighting factors (w_T)

Organ/Tissue	$ICRP_{60}$	$ICRP_{103}$	$ICRP_{103}/ICRP_{60}$
Gonads	0.20	0.08	0.4
Colon	0.12	0.12	1.0
Lungs	0.12	0.12	1.0
Red bone marrow	0.12	0.12	1.0
Stomach	0.12	0.12	1.0
Bladder	0.05	0.04	0.8
Breast	0.05	0.12	2.4
Liver	0.05	0.04	0.8
Oesophagus	0.05	0.04	0.8
Thyroid	0.05	0.04	0.8
Bone surface	0.01	0.01	1.0
Skin	0.01	0.01	1.0
Brain		0.01	
Salivary glands		0.01	
Remainder	0.05*	0.01+	

* ICRP60 remainder tissues/organs: adrenals, brain, kidneys, muscle, pancreas, small intestine, large intestine, spleen, thymus, uterus.
+ ICRP103 remainder tissues/organs: adrenals, extrathoracic tissue, gall bladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate, small intestine, spleen, thymus, uterus/cervix.

Results and discussion

The rate of return (address change, retired, deceased) was about 1% and the rate of explicit refusal was about 0.2%. Table 4 shows the response rates for the three broad categories of health care providers (medical, dental and chiropractic) as well as for various types of hospital departments.

In terms of number of healthcare providers, the overall response rate is 42% corresponding to 3486 respondents. In terms of X-ray units, the overall response rate is 45%, corresponding to 7878 units.

During the 1998 survey, a sample of 3000 establishments was contacted and at the end of the survey the response rate was 60% [Aroua et al. 2002a]. About 1800 participants sent their data, which is nearly half the number of respondents in the 2008 survey.

Two participants over three registered their data online. Half of the rest sent their data in electronic form and the other half in paper form.

Table 4: Response rates for the 2008 Swiss nationwide survey

Category of	Healthcare providers			X-ray units		
healthcare providers	Total	Respondents	Rate (%)	Total	Respondents	Rate (%)
All categories	8247	3486	42	17391	7878	45
Medical	4587	1953	43	6704	3376	50
Dental	3526	1461	41	10553	4418	42
Chiropractic	134	89	66	134	89	66
Radiology institutes	85	39	46	347	170	49
Hospital departments (all)	383	249	65	2394	1519	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

Table 5 gives the range of regional variation of the response rates. The seven regions of Switzerland are presented in Figure 1. The cantons that constitute each region are given in table 6. If all categories are summed up, the regional variation is in the range 41-46%. The detailed regional response rates are given in Appendix 5.

Table 5: Regional distribution of the response rates (%)
for the 2008 Swiss nationwide survey. CH : Whole Switzerland.

Category of	Total	Region							CH
health care providers	#	1	2	3	4	5	6	7	
All categories	8247	40	43	44	41	45	42	46	42
Medical	4587	40	43	43	42	45	41	45	43
Dental	3526	40	42	44	37	43	42	47	41
Chiropractic	134	50	66	64	81	87	63	100	66
Radiology institutes	85	35	53	50	73	27	100	33	46
Hospital departments (all)	383	60	63	71	64	69	59	77	65
in university hospitals	53	43	36	57	78	—	—	—	49
in canton hospitals	62	—	60	83	50	60	73	—	65
in district hospitals	111	59	79	78	67	74	50	83	72
in state hospitals	14	—	40	100	86	—	—	—	71
in private hospitals	132	74	55	62	43	80	43	83	66
in houses for the elderly	11	—	60	—	100	—	—	50	55

Figure 1: The Seven region of Switzerland
according to the Swiss Federal Office of Statistics

Table 6: The Cantons included in the seven regions of Switzerland

Region	Cantons
1. Lake Geneva	VD / VS / GE
2. Espace Mittelland	BE / FR / SO / NE / JU
3. Northwestern Switzerland	BS / BL / AG
4. Zurich	ZH
5. Eastern Switzerland	GL / SH / AR / AI / SG / GR / TG
6. Central Switzerland	LU / UR / SZ / OW / NW / ZG
7. Ticino	TI

A sensitivity analysis was performed in order to assess the effect on the result if the non respondents had features that are different from those of the respondents, in particular the frequencies of examinations performed. The hypothesis that the non-participants perform 20% more or 20% less examinations than the participants resulted in an average 10% difference in the national examination frequencies. As shown in Appendix 6, the difference is smaller for interventional radiology (-3%, +4%) and bigger for dental radiology (-12%, +12%). For dental radiology, the number of non-participants is higher than that of participants.

Table 7 shows the annual number of examinations performed in Switzerland in 2008 (7.7M population), the number per thousand population, as well as the associated annual collective dose and the average per caput effective dose delivered by the whole medical radiodiagnostics as well as by the various radiological modalities. The detailed frequency and dose results are provided in Appendix 9.

Table 7: 2008 Swiss annual frequency and dose data

Radiological modality	Number of examinations (in thousands)	Collective dose (man.Sv)	Number of examinations per 1000 population	Effective dose per caput (mSv)
Radiography	6000	1330	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	6150	100	0.8
Dental radiology	5430	63	700	0.01
Mammography	387	62	50	0.01
Bone densitometry	117	0. 31	15	0.00004
Total	13'000	9100	1700	1.2

This investigation revealed that the total number of X-ray examinations carried out in Switzerland was 13 M per year in 2008, corresponding to 1.7 examinations per caput. The associated collective effective dose accounts to about 9100 man Sv which, reported to the Swiss population gives an average effective dose of 1.2 mSv per caput. In the 2003 review the average effective dose was also estimated to 1.2 mSv per caput per year. Therefore it registered no change although the frequency increased during this 5-year period. This is due to the change of the dose vector. In fact the updated effective doses per examination for radiographies are significantly lower than older values. The use of the dose vector established in 1998 with the 2008 frequency data would have resulted in an average effective dose of 1.4 mSv per caput.

Figure 2 presents the distribution of the total annual number of examinations and the total annual collective dose over the various radiological modalities. It shows that the highest contributions to the total number of examinations come from radiography (46%) and dental radiology (42%). However, in terms of the collective effective dose the contribution of radiography drops to 14.6% and that of dental radiology to less than 1%. On the contrary CT which contributes 6% to the number of examinations is responsible of more than 2/3 of the collective effective dose. Similarly, interventional radiology (diagnostic and therapeutic) whose contribution in terms of frequency of examinations is only 0.8% delivers nearly 12% of the collective effective dose.

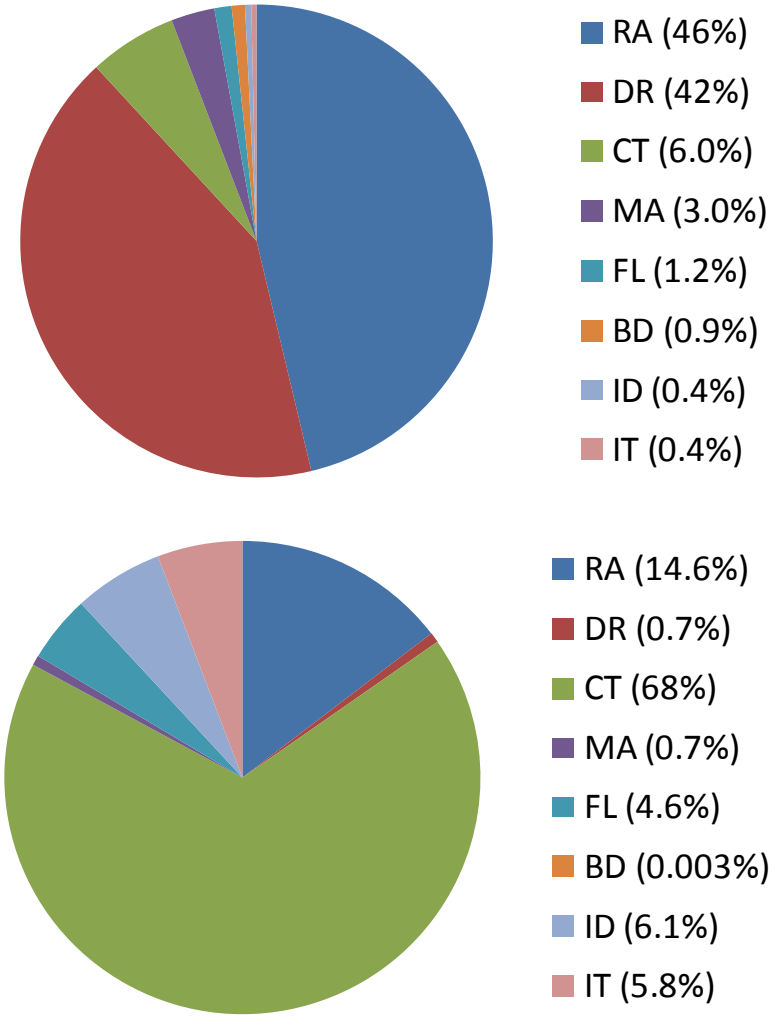

Figure 2: Distribution of the total annual number of examinations (upper part) and the total annual collective dose (lower part) over the various radiological modalities: radiography (RA), conventional fluoroscopy (FL), diagnostic interventional radiology (ID), therapeutic interventional radiology (IT),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

Figures 3 to 6 present the 3 most frequent examinations and the 3 examinations with the highest dose contribution in radiography, interventional radiology, computed tomography, and dental radiology.

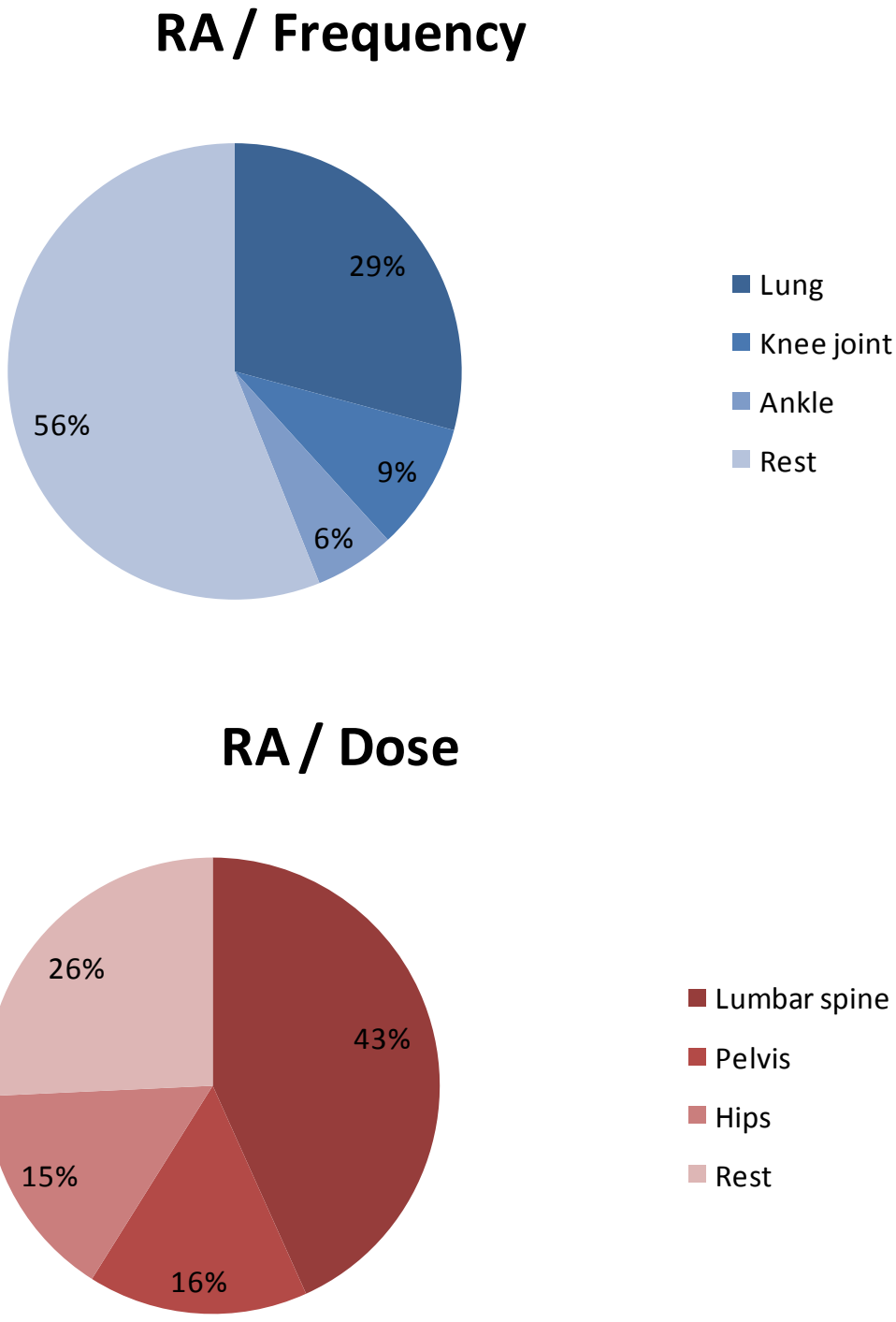

Figure 3: The 3 most frequent examinations and the 3 examinations with the highest dose contribution in radiography

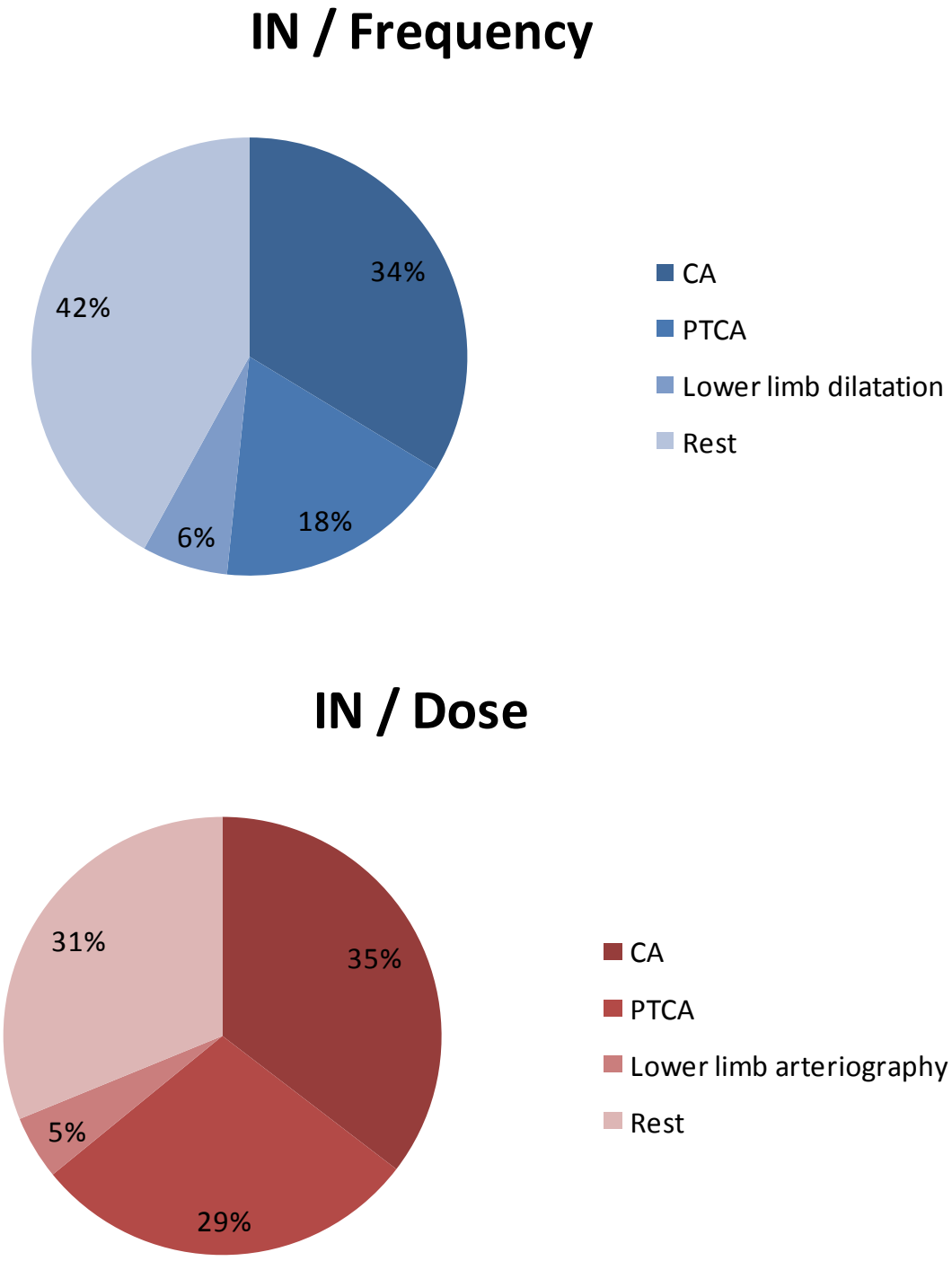

Figure 4: The 3 most frequent examinations and the 3 examinations with the highest dose contribution in interventional radiology (both diagnostic and therapeutic)

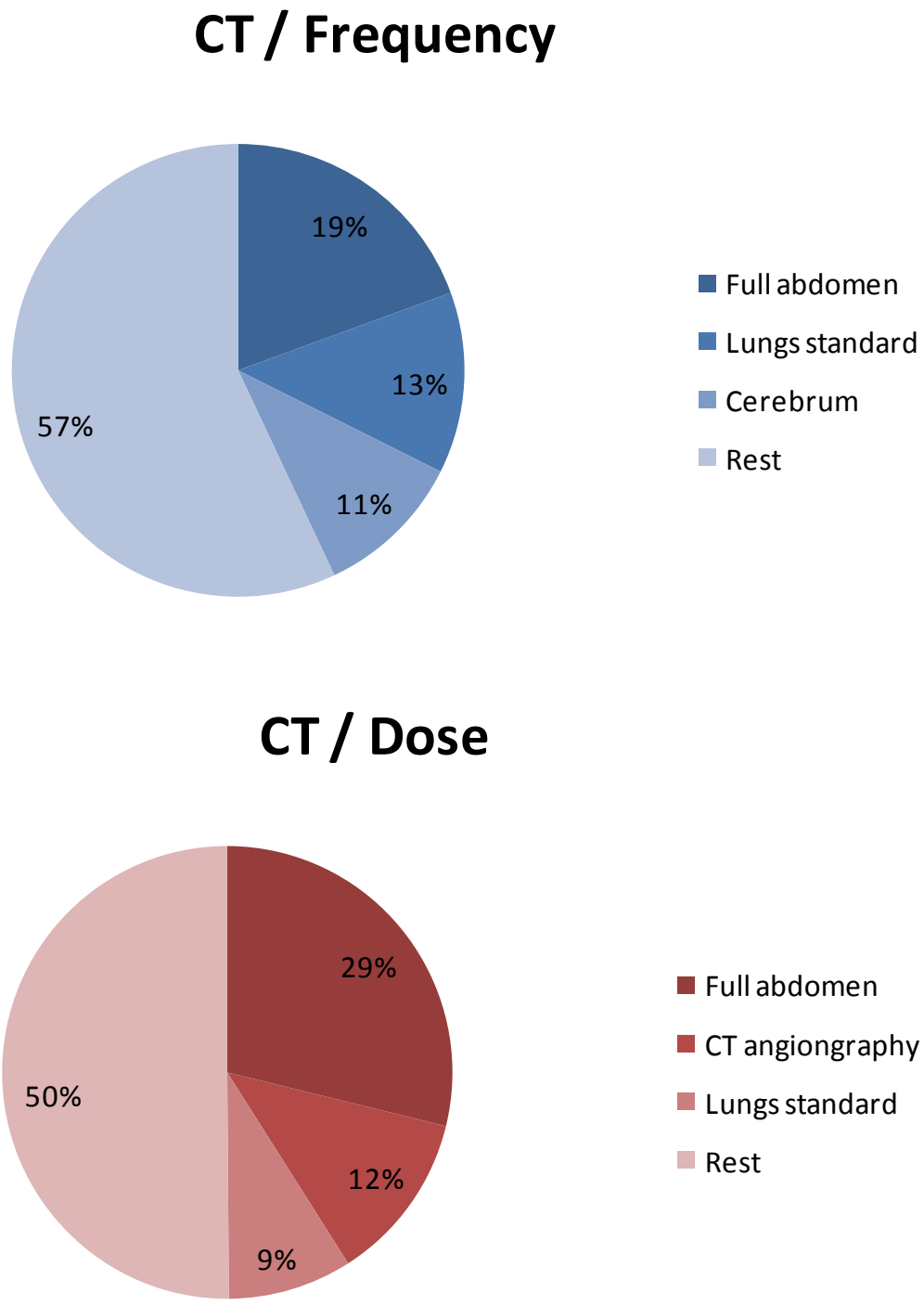

Figure 5: The 3 most frequent examinations and the 3 examinations with the highest dose contribution in computed tomography

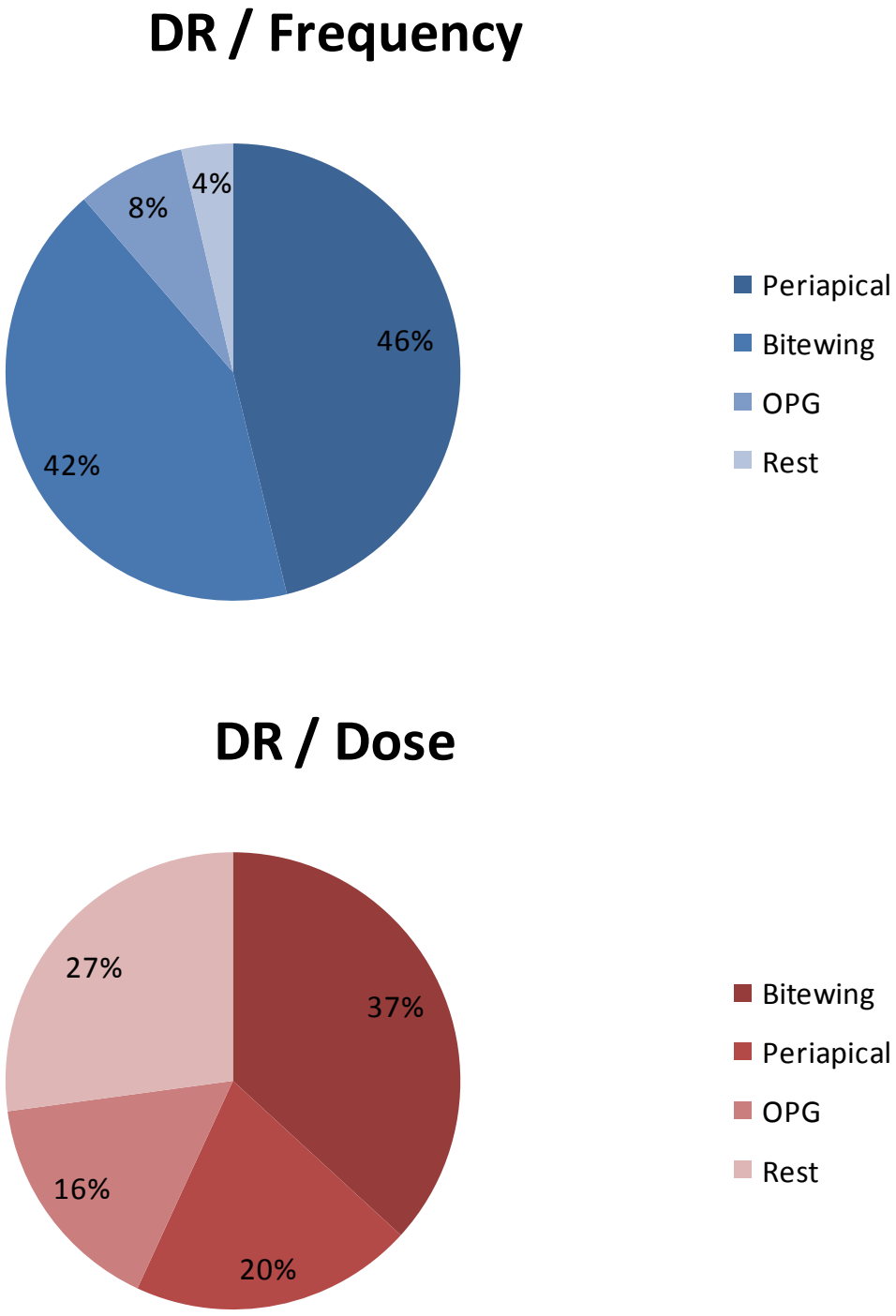

Figure 6: The 3 most frequent examinations and the 3 examinations with the highest dose contribution in dental radiology

Figure 7 shows the frequency and dose contribution of the different healthcare providers (The details are given in Appendices 7 and 8). Hospitals undertake 34.6% of the examinations and are responsible of 81% of the collective effective dose. Radiology institutes contribute 4% in terms of frequency and 12.6% in terms of the collective effective dose. Dental practices perform almost 41% of the examinations and are responsible of only 0.7% of the collective dose. Medical practices perform a fifth of the examinations and contribute 5.3% to the collective effective dose. Chiropractors are responsible for 0.5% of the frequencies and 0.5% of the collective effective dose.

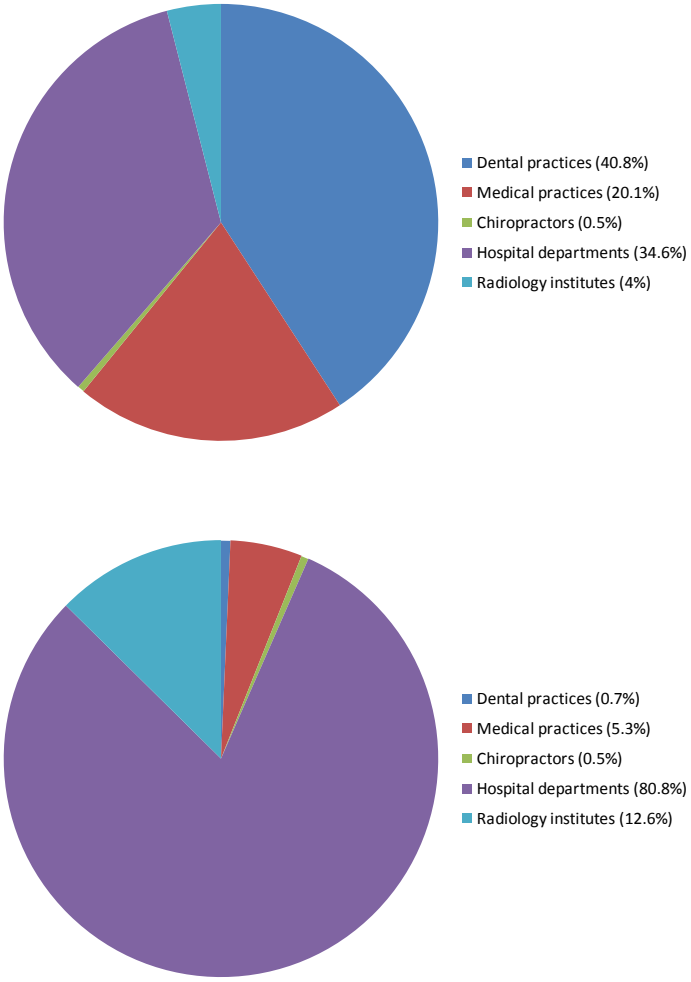

Figure 7: Frequency (upper part) and dose (lower part) contribution of the different healthcare providers

Tables 8 and 9 present the frequency and dose contribution of the different healthcare providers for the 8 radiological modalities considered.

Table 8: Frequency contribution of the different healthcare providers (%) for the 8 radiological modalities considered

	Dental practices	Medical practices	Chiropractors	Hospital departments	Radiology institutes
RA	0	42.5	1.1	52.8	3.7
FL	0	6.1	0	77.1	16.8
ID	0	0	0	99.9	0.1
IT	0	0	0	97.5	2.5
CT	1.5	0	0	83.3	15.2
DR	97.2	0.2	0	2.4	0.1
MA	0	7.7	0	61.5	30.8
BD	0	2.4	0	75.9	21.7

Table 9: Dose contribution of the different healthcare providers (%) for the 8 radiological modalities considered

	Dental practices	Medical practices	Chiropractors	Hospital departments	Radiology institutes
RA	0	34	3.7	55	6.4
FL	0	5.1	0	87	8.0
ID	0	0	0	100	0.05
IT	0	0	0	100	0.003
CT	0.1	0	0	83.5	16.4
DR	92.0	2.1	0	5.1	0.8
MA	0	7.7	0	61.5	30.8
BD	0	2.4	0	77.5	20.2

Table 10 compares the frequency and dose data obtained in the present study with the data established in Switzerland in 1998.

Table 10: 2008/1998 ratios of the frequency and dose in Switzerland

Radiological modality	Number of examinations	Collective dose	Number of examinations / 1000 population	Effective dose / caput
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

The first two columns of the table present the ratio of examination frequency and collective effective dose relative to 2008 and 1998 (absolute values) and the last two columns the ratio of the number of examinations per 1000 population and the average effective dose per caput. 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 1000 population and the average effective doses per caput were compared.

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 number of X-ray units was available and we chose to use it since it leads to more accurate results. This different approach may also explain some of the differences between the examination frequencies in 1998 and 2008 surveys, i.e. the 21% increase in conventional and dental radiographies.

The number of radiographies registered a 20% increase but the average effective dose per caput decreased by more than a factor 2. This is due the significant reduction in the average effective dose per radiography for many types of examinations.

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 of effective dose per caput of 90%. This

can be explained by the fact that cases previously treated with open surgery may be now safely and effectively treated by interventional procedures [Balter et al. 2008]. Accordingly, the increase in the dose delivered by this kind of procedures may be attributed to the fact that more complex cases may now be treated by interventional radiology, resulting, however, in higher patient doses [Balter et al. 2008].

The main increase in the collective effective dose in a decade may be attributed to the increase in CT (286% in terms of the collective effective dose since 1998). The increase in the number of CT examinations had already been observed [Aroua et al. 2007a] and attributed to the technology advance in CT scanners that led to the change of 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, as they will be considered in a specific survey dedicated to the dose delivered in nuclear medicine [Roser 2011].

The number of bone densitometry examinations has notably increased (3.36 times) since 1998; however, its associated dose was too low to significantly affect the collective effective dose (see Table 7). Some increase in these examinations may be attributed to the population ageing but also to the fact that bone densitometry examinations are performed for the diagnosis of osteoporosis as well as the follow-up of osteoporosis treatments.

Table 11 presents the number of all examinations and number of CT examinations (per 1000 population), average effective dose due to radiodiagnostics and average effective dose due to CT, for 1998, 2003 and 2008. Both the frequency of CT examinations and the associated collective effective dose registered a steady increase since 1998: respectively a factor of 2.2 and 2.9 in a decade. It should be noted that the increase was higher between 1998 and 2003 than between 2003 and 2008. In one decade, the contribution of CT to the total medical X-rays increased from 3.4% to 6% in terms of the frequency and from 28% to 68% in terms of the collective effective dose.

Table 11: Number of all examinations and number of CT examinations (per 1000 population), average effective dose due to radiodiagnostics and average effective dose due to CT, for 1998, 2003 and 2008 (absolute and relative values)

Year	N /1000 population		CT /Total	E (mSv/caput)		CT /Total
	Total	CT	(%)	Total	CT	(%)
1998	1340	46.2	3.4	1.0	0.28	28
2003	1470	76.7	5.2	1.2	0.56	47
2008	1680	100	6.0	1.2	0.80	68

Ratio	N/1000 population		E (mSv/caput)	
	Total	CT	Total	CT
2003/1998	1.10	1.66	1.20	2.00
2008/2003	1.14	1.32	1.00	1.43
2008/1998	1.26	2.19	1.20	2.86

Table 12 shows the evolution of the number of X-ray Units in Switzerland from 1998 and 2008. The increase in the number of CT scanners, and dental and mammography X-ray units in a decade (27%, 22% and 4% respectively) may explain the part of the increase in the frequency of examinations for those radiological modalities.

Table 12: Number of X-ray Units in Switzerland

Specialty	Radiological modality	Code	1998*	2008**	08/98
Medical	Radiography	RA	—	4937	
	Fluoroscopy (mobile)	RD	—	476	
	Radiography & fluoroscopy	RAD	—	760	
	Radiography & fluoroscopy (Intensive Dose)	RDI	—	127	
	Computed tomography	CT	187	238	1.27
	Mammography	MAM	240	249	1.04
	Bone densitometry	KDM	—	147	
	Total "Medical"	—	8419	6934	0.82
Dental	Intra-oral (< 70 kV)	RKL	—	8572	
	Orthopantomography	OPG	—	1171	
	Teleradiography	FR		4	
	Orthopantomography & Teleradiography	OPF	—	661	
	Dental volume tomography	DVT	—	49	
	Total "Dental"	—	8583	10457	1.22
	Total "Medial + Dental"	—	17002	17391	1.02

* UNSCEAR 2000 ** BEBERA file received from FOPH

Table 13 shows the contribution of medical exposure to the total irradiation of the population for various countries. It ranges from about 15% in Finland to as high as 48% in the USA.

Table 13: Contribution of medical exposure to the total irradiation of the population

Country	CH	NO	D	USA	UK	FI
E (mSv/caput)	4.0	4.4	3.9	6.2	2.7	3.7
Contributions (%)						
Radon	40	46	28	37	49	54.2
Medicine	**30**	**24**	**46**	**48**	**16**	**14.4**
NM	OUT	IN	IN	IN	OUT	IN
Cosmic	10	7	7.7	5	12	8.9
Terrestrial	9	14	10	3	13	12.7
Internal	9	7	7.7	5	9	9.8
Others	2	1	0.5	2	1	—

Table 14 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 USA. The data presented in the 2008 UNSCEAR report for countries with similar healthcare systems as Switzerland (level I), which covers the decade 1997-2007, is also included for comparison.

Table 14: Frequency and dose comparisons with data reported in other countries

Country	Number of X-ray examinations per 1000 population	Annual per caput effective dose due to medical X-rays (mSv)
UNSCEAR – Health level I (1997-2007)	1607	1.9
USA (2006)	1257	2.2
France (2007) *	1152	1.2
Germany (2008)	1650	1.7
United Kingdom (2008)	752	0.4
The Netherlands (2008)	573	0.7
Norway (2008) **	670	1.1
Finland (2008)	717	0.45
Switzerland (2008)	1700	1.2

* Excluding therapeutic interventional procedures – ** Excluding dental radiology

For the Netherlands, France and the USA nuclear medicine was included in the originally reported figures and had to be removed in Table 14 for the comparison of the X-ray component.

The annual number of examinations per 1000 population established in this work (1700) is the highest among the countries of interest. This is due to the high frequency of dental X-ray examinations in Switzerland (see also Table 18). The average annual effective dose per caput 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 USA.

Table 15 gives nuclear medicine frequency and dose comparisons with data reported in other countries. The Swiss frequency and dose values are relatively low and compare with those registered in Norway. They are well below the figures reported in the USA. If we consider the contribution of nuclear medicine to the total average effective dose (radiodiagnostics + nuclear medicine), one can observe the existence of three categories of countries with NM contributions amounting to 5% such as Switzerland, Germany and the Scandinavian countries, 10% such as France and the Netherlands, and 30% in the case of the USA.

Table 15: Nuclear medicine (NM) frequency and dose, and total dose, comparisons with data reported in other countries

Country	Number of NM procedures per 1000 population	Annual per caput E due to NM (mSv)	Total annual per caput E (mSv)	E ratio NM / Total (%)
UNSCEAR – Health level I (1997-2007)	22.1	0.12	2.0	6
USA (2006)	60	0.8	3.0	27
France (2007)	18	0.13	1.3	10
Germany (2008)	37	0.1	1.8	5.6
The Netherlands (2008)	24	0.095	0.8	12
Norway (2008) *	9.7	0.054	1.1	4.9
Finland (2008)	7.7	0.03	0.48	6.3
Switzerland (2010) **	13	0.06	1.3	4.6

* [Frede Unhjem 2011] – ** [Roser 2011]

Table 16 compares the contribution of CT to the total number of examinations and to the collective effective dose in Switzerland with that reported in other countries. It shows clearly that the same pattern observed in Switzerland is registered elsewhere: a 10-20% contribution in terms of frequencies is reflected into up to a 2/3 contribution in terms of collective effective dose. In the case of Norway the CT frequency contribution is even higher (29%), since dental radiology is not considered.

Table 16: Contribution of computed tomography (%)

Country	To the total number of X-ray examinations	To the total collective dose
UNSCEAR – Health level I (1997-2007)	8	47
USA (2006)	18	66
France (2007) *	10	65
Germany (2008)	8	60
United Kingdom (2008)	7	67
The Netherlands (2008)	11	53
Norway (2008) **	29	80
Finland (2008)	8.3	58
Switzerland (2008)	6	68

* Excluding therapeutic interventional procedures – ** Excluding dental radiology.

Table 17 compares the contribution of interventional radiology to the total number of examinations and to the collective effective dose in Switzerland with that reported in other countries. The Swiss frequency contribution data (about 1%) compare with those of other countries except the USA and the UK where the figures are relatively high (5% and 12% respectively) and Norway where the figure is relatively low (0.2%). The contribution of interventional radiology to the total collective effective dose ranges from 6% in France (where therapeutic procedures are excluded) to nearly 20% in Germany and the USA. The Swiss figure (12%) compares with that other countries.

Table 17: Contribution of interventional radiology both diagnostic and therapeutic (%)

Country	To the total number of X-ray examinations	To the total collective effective dose
UNSCEAR – Health level I (1997-2007)	0.5	4.3
USA (2006)	5	19
France (2007) *	0.6	6.1
Germany (2008)	2	19
United Kingdom (2008)	12	13
Norway (2008) **	0.2	10
Finland (2008)	0.8	14
Switzerland (2008)	0.8	12

* Excluding therapeutic interventional procedures – ** Excluding dental radiology [Almén 2011]

Table 18 compares the frequency and dose data obtained in the present study for dental radiology with the data reported recently by seven countries. The total annual number of examinations per 1000 population established in this work (1700) is higher than the figures of the other countries. This is due to the high frequency of dental X-ray examinations in Switzerland: 700 per year per 1000 population, compared to 289 in France and 193 in the UK. The US frequency figure for dental radiology seems to be too low.

Table 18: Dental radiology frequency and dose comparisons with data reported in other countries (%)

Country	Number of dental examinations per 1000 population	Annual per caput E due to dental radiology (microSv)	% of total number of X-ray examinations	% of total collective dose
UNSCEAR – Health level I (1997-2007)	275	6	17	0.3
USA (2006)	8.8	8	0.7	0.4
France (2007)	289	3	25	0.3
Germany (2008)	600	≤10	37	0.3
United Kingdom (2008)	193	2	26	0.5
Norway (2008) *	1173	26.2	64	2.3
Finland (2008)	385	3	30	0.7
Switzerland (2008)	700	8	42	0.7

* [NRPA 2009]

Conclusion

This work updated the frequency and collective effective dose data for medical and dental X-ray examinations in Switzerland for the year 2008. The average frequency of X-ray examinations was found to be 1.7 per caput with an associated average annual effective dose of 1.2 mSv/caput. There was no increase of the average effective dose since 2003 although the frequency has increased due to the fact that the effective doses per examination decreased significantly for radiography. The survey showed that Switzerland stands at the same level as other countries with similar healthcare systems in terms of collective effective dose. 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 regularly perform surveys in order to follow the trends in population exposure. In addition, such surveys, along with the definition and implementation of diagnostic reference levels may identify the points to focus for future optimisation campaigns.

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