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ADULT REFERENCE LEVELS IN DIAGNOSTIC AND INTERVENTIONAL RADIOLOGY FOR TEMPORARY USE IN SWITZERLAND

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This work aims at establishing a set of diagnostic reference levels (DRLs) for various types of examinations performed in diagnostic and interventional radiology. The average doses for 257 types of radiological examinations were established during the 1998 nationwide survey on the exposure of the Swiss population by radiodiagnostics. They were calculated using appropriate dosimetric models and average technical parameters. The DRLs were derived from the average doses using a multiplying factor of 1.5. The DRLs obtained were rounded and compared to the data reported in the literature. The results are in most cases comparable to the DRLs determined by the 3rd-quartile method. These discrepancies registered in some cases, particularly for complex examinations, can be explained by significant differences in the protocols and/or the technical parameters used. A set of DRLs is proposed for a large number of examinations to be used in Switzerland as temporary values until a national dosimetric database is set up.

INTRODUCTION

The definition, establishment and implementation of diagnostic reference levels (DRL) have become in recent years a central issue in the management of the radiation dose delivered to the patient in diagnostic and interventional radiology. Several scientific meetings showed an increasing interest for this subject such as the Workshops of 1993[(1)], Luxembourg in 1997[(2)], Malmö in 1999[(3)] and Dublin in 1999[(4)], the Hiroshima IRPA-10 Congress in 2000[(5)], the Malaga IAEA Conference in 2001[(6)]. The European Radiation Protection, Education and Training Organisation (ERPET) has dedicated one of its training sessions (Passau, 2000) to the establishment of DRLs[(7)], while the *Applied Radiation and Isotopes* journal has published a whole issue on patient doses in diagnostic radiology[(8)].

The historical evolution of the DRL concept and the various quantities proposed are described by different authors[(9,10)]. Several works reported in the literature in recent years focused on the review of the different concepts related to DRLs[(11)], their role, usefulness, impact and associated problems[(12)], the various dosimetric quantities considered[(13)], and the practical difficulties encountered in the establishment and implementation of DRLs[(14–22)]. There is a growing need for harmonisation of the concepts and quantities[(23)]. The different approaches to DRLs at the international level have been summarised by the ICRP in a recent report[(24)].

Setting up DRLs is relatively easy in the case of simple examinations such as conventional radiographic views. However, for complex examinations such as dose-intensive procedures involving fluoroscopy or CT (computed tomography) examinations, establishing a DRL is a difficult task due to the large variability of the fluoroscopy time and the number of images (number of series and slice number and thickness in case of CT) leading to a wide distribution of patient doses. This is due to several factors including the often loose definition of the examination, differences in the techniques and protocols used, the complexity of the case and the experience of the radiologist.

In general, the DRLs are based on dosimetric surveys. The 3rd-quartile method has been proposed about a decade ago in the UK by the NRPB and is now widely used[(25)]. This method prescribes the use as a DRL of a dose value corresponding to $^3/_4$ of the dose distribution established by the survey. The NRPB issued recently the 2000 review of the DRLs recommended for use in the UK and based on this method[(26)].

In the absence of a dose distribution, another method is suggested consisting in multiplying the established average dose by an appropriate factor. The surveyed dose distributions are often extended to the right side. A recent limited investigation which covered a couple of Swiss hospitals and a few examinations indicated that the ratio between 75% and the mean value of the dose distribution lies in most cases between 1.2 and 1.3 but can reach 1.5 in a few cases. To be on the conservative side the factor to be applied in this work is 1.5. This method and the

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1.5-factor were used in a recent work to establish DRLs for cardiology at the European level[27].

In Switzerland no recent dose distributions are available. Those proposed by Mini as a basis for the establishment of national DRLs[28] were determined in 1992 and cover a small number of types of examinations only. In addition, more recent dose distributions were established for a few examination types: four angiographic examinations at the Bern University Hospital[29], and ten examinations including fluoroscopy, angiography and coronary dilation at the Lausanne University Hospital[30]. Moreover, a methodology was recently proposed for the establishment of DRLs for paediatric CT[31].

The Swiss strategy for establishing DRLs consists in the following elements:

(1) Launching nationwide dosimetric surveys in order to establish national DRLs for the various radiological modalities. A first dosimetric survey, carried out in 2002, focused on CT examinations (10 hospitals were covered and 15 CT examinations investigated). The second survey, carried out in 2003, focused on dose-intensive fluoroscopic examinations (five university hospitals were covered and eight diagnostic and interventional examinations investigated).
(2) Until the results of these surveys are available, European DRL values are adopted when possible. This is the case of a number of radiographic examinations for which the DRL values proposed at the European level are adopted in Switzerland: skull, cervical spine, chest, thoracic spine, abdomen, lumbar spine, pelvis and hip. A directive was issued by the Swiss Federal Office of Public Health concerning these DRLs and containing the following information: definitions, proposed DRLs, application of DRLs, measurement of the entrance surface dose (ESD), calculation of the ESD. Moreover, a computer software was developed allowing the practitioners to assess online the ESD for a given radiographic examination and to compare it with the corresponding DRL.
(3) In the absence of European data, temporary DRLs are calculated from the average doses established in the framework of the 1998 nationwide survey on the exposure of the public by radiodiagnostics in Switzerland.

This paper presents the work undertaken in order to establish a set of provisional DRLs for various types of examinations performed in diagnostic and interventional radiology in Switzerland, based on average patient effective doses.

METHODS

Average-dose values are available in Switzerland for 257 types of examinations covering the various modalities of diagnostic and interventional radiology. They have been established by dosimetric modelling considering average technical parameters for each type of examination, in the framework of the 1998 nationwide survey on the exposure of the Swiss population by medical radiology[32,33].

Various operational dose quantities are used to establish DRLs depending on the radiological modality considered as presented in Table 1.

In the case of a radiographic projection, the operational dose quantity is the ESD (mGy), which takes this empirically based form:

$$\mathrm{ESD} = K \cdot \left(\frac{U}{100}\right)^2 \cdot \frac{3}{F_\mathrm{A}} \cdot Q \cdot \frac{1}{(\mathrm{FSD})^2} \cdot \mathrm{BSF},$$

where U (kV) is the tube voltage, Q (mAs) is the tube current–time product, F_A is the filtration expressed

Table 1. Dosimetric quantities used to establish the diagnostic reference levels.

Modality	Dosimetric quantity	Abbreviation	Unit
Radiography	Entrance surface dose, per view	ESD	mGy
	Dose-area product, per examination	DAP	Gy cm^2
Mammography	Air Kerma at the breast surface, per view	ESAK	mGy
Fluoroscopy	Dose-area product, per examination	DAP	Gy cm^2
Angiography and	Dose-area product, per examination	DAP	Gy cm^2
interventional radiology	Number of images, per examination	—	—
	Fluoroscopy time, per examination	—	min
Computed tomography	Weighted CT dose index, per slice or rotation	$\mathrm{CTDI_w}$	mGy
	Dose–length product, per examination	DLP	mGy cm
Dental radiology	Entrance surface dose, per view for intra-oral exminations (apical, bitewing)	ESD	mGy
	Dose–width product for OPG	DWP	mGy mm

in mm of aluminium, FSD is the focus-to-skin distance, and BSF is the back scattering factor. K (mGy m^2 per mAs) is an empirically determined constant specifying the radiological unit; a typical value of 0.1 mGy m^2 per mAs is adopted.

In the case of a fluoroscopy examination, the ESD takes the same form as above, Q being replaced by the current I (in mA) times the exposure time t (in s). For this category of examinations, the operational dose quantity commonly used is the dose-area product (DAP usually expressed in Gy cm^2), which can be computed by multiplying the ESD by the field size at the entrance of the patient.

In the case of a CT examination, the operational dose quantity used for a slice is the weighted computed tomography dose index ($CTDI_w$) measured in mGy representing the average dose that would be absorbed by the central slice within a 100 mm range of contiguous scanning, and defined as follows:

$$CTDI_w = 1/3\ CTDI_c + 2/3\ CTDI_p,$$

where $CTDI_c$ (mGy) is measured at the centre of a homogeneous cylinder of polymethyl-methacrylate (PMMA), with diameters of 16 cm (head) or 32 cm (body), and $CTDI_p$ (mGy) is measured 10 mm below the surface of the phantom, and represents an average of measurements at four different locations around the periphery of that phantom.

The operational dose quantity used for a full CT examination is the dose–length product (DLP) measured in mGy cm and defined as follows:

$$DLP = CTDI_w \cdot t \cdot n,$$

Where t (cm) relates to the slice thickness and n relates to the number of slices.

From the average values of the operational dose quantities, the DRLs are established by multiplying the average values by a factor 1.5.

RESULTS AND DISCUSSION

The technical parameters related to the full set of 257 types of examinations and used to establish the corresponding DRLs are given in the detailed report of the 1998 nationwide survey available on-line[34]. In cases where the 1998 data are not used anymore, the technical parameters where modified accordingly.

As an example of radiographic examinations, Table 2 gives the average technical parameters for chest radiography (lateral view). The average ESD computed from these parameters equals 0.26 mSv. This leads, using the 1.5 multiplying factor, to a DRL of 0.4 mSv. This value is lower than the DRL of 1.5 proposed at the European level[35]. The technical parameters considered in the calculation are still in use. A survey that addressed four care-providing centres revealed that two of them use the same technical parameters, the third one uses a tube voltage of 150 kV, and the fourth one uses a tube voltage of 150 kV and a current–time product of 14 mAs. This leads to a DRL of 0.56 and 1.6 mSv respectively.

Concerning the examinations involving fluoroscopy, two examples are presented for illustration: barium meal (Table 3), Endoscopic retrograde cholangio pancreatography (ERCP) (Table 4) and cerebral angiography (Table 5).

Concerning barium mean, the technical parameters lead to a DRL in terms of total DAP of 110 Gy cm^2, which is four-times higher than the 25 Gy cm^2 value proposed at the European level[35] and reported in the literature[36], and about one order of magnitude higher than the figure published recently by NRPB (13 Gy cm^2)[26]. A minimalist definition of this examination, i.e. 1 radiography

Table 2. Typical technical parameters for chest radiography (lateral view).

Tube voltage (kVp)	125
Current–time product (mAs)	5
Filtration (mm Al)	3
Focus-to-film distance (cm)	200
Field size at the skin entrance plane (cm^2)	30×36
Sensitivity	400
Grid	Yes

Table 3. Typical technical parameters for barium meal.

Technical parameter	Part of the body		
	Oesophagus	Thorax	Abdomen
Fluoroscopy time (s)	—	120	300
Tube voltage (kVp)	65	70	80
Tube current (mA)	1	2.5	3
Focus-to-image intensifier distance (cm)	—	60	60
Field size (cm^2)	10 × 12	16 × 35	30 × 40
Number of images	6	6	6

Table 4. Typical technical parameters for ERCP.

Part of the body exposed	Abdomen
Fluoroscopy time (s)	1200
Tube voltage (kVp)	80
Tube current (mA)	3
Focus-to-image intensifier distance (cm)	60
Field size (cm^2)	30×40
Number of images	8

Table 5. Typical technical parameters for cerebral angiography.

Cine mode	
Tube voltage (kVp)	80
Tube current (mA)	300
Focus-to-image intensifier distance (cm)	100
Number of sequences	10
Total number of images	250
Exposure time per image (ms)	25
Total effective exposure time (s)	6.25
Fluoroscopy	
Tube voltage (kVp)	70
Tube current (mA)	1.5
Fluoroscopy time (s)	300
Diameter of the image intensifier (in.)	9
Field size (cm^2)	80

per region and 1 min of fluoroscopy for the thoracic and abdominal regions, would lead to a total DAP for the examination of 20 Gy cm^2 (9.8 Gy cm^2 radiography and 10.5 Gy cm^2 fluoroscopy), which is close to the figure reported in the literature (20 Gy cm^2). This seems too low to be representative of typical barium meal examination as it is practiced in Switzerland and which extends to the whole stomach. In other places, such as UK, barium meal is limited to the oesophagus region and involves five images only[26], corresponding to the six images taken in Switzerland in the oesophagus part of barium meal. This explains the big differences found between the figure found here and the data of the literature. Another suspected source of discrepancy is a bad beam collimation when viewing the oesophagus region.

For ERCP, the result obtained here (220 Gy cm^2) is extremely high compared to that found in the literature. This is due to the technical parameters used. In this work 8 images and 1200 s of fluoroscopy are considered, whereas in the UK for instance, the average figures are 4 images and 271 s of fluoroscopy[26]. An investigation with a few Swiss radiologists revealed that in Switzerland, ERCP is mainly a therapeutic (interventional) procedure and that diagnostic ERCP is no more performed by X rays but using other non-X-ray radiological modalities such as Magnetic resonance imaging (MRI). The differences in DAP obviously come from differences in the definition of the examination.

Table 6. Typical technical parameters for CT of the abdomen.

Technical parameter	Series 1	Series 2
Number of scans	1	1
Plane of first slice	Hepatic dome	Iliac crest
Plane of last slice	Iliac crest	Pubic symphysis
Mode	Helical	Axial
Slice thickness (mm)	8	10
Slice spacing (mm)	1	0
Pitch (overlap)	1.12	1
Length of scanned volume (mm)	200	200
Tube voltage (kVp)	120	120
Tube current (mA)	220	260
Rotation time (s)	0.75	1
$CTDI_w$ (mGy)	11.4	17.8

Table 7. Comparison of DRLs for a few radiographic views.

Examination	ESD (mGy) this work	ESD (mGy) literature[24]
Skull PA/AP	5.4	5
Skull lateral	3.5	3
Cervical spine AP	3.1	1.2
Chest PA	0.2	0.1–0.4
Chest lateral	0.4	1.5
Thoracic spine AP	7	7
Thoracic spine lateral	21	20
Abdomen AP	7	4.3–10
Lumbar spine AP/PA	8.7	3.9–10
Lumbar spine lateral	26	30
Pelvis AP	7.8	10
Hip AP	4.7	10

As regards cerebral angiography the technical parameters lead to DRL of 50 Gy cm^2. Padovani *et al.*[37] reported recently a DRL value of 102 Gy cm^2 established from a longer fluoroscopy time: 12 min instead of 5 min in this work.

As regards CT examinations, the protocol used for abdomen CT is presented in Table 6. The technical parameters considered for this type of examination lead to a DRL in terms of $CTDI_w$ per slice of 20 mGy and in terms of DLP per examination of 710 mGy cm. These figures are slightly lower than the DRLs proposed at the European level[38]: a $CTDI_w$ per slice of 35 mGy and DLP of 870 mGy cm.

Tables 7–9 present the DRLs established for a number of examinations covering radiography, fluoroscopy and CT modalities and compared to the data reported in the literature. In the absence of detailed information concerning the technical

Table 8. Comparison of DRLs for a few examinations involving fluoroscopy.

Examination	DAP (Gy cm^2) this work	DAP (Gy cm^2) literature	Reference
IVU	35	40	(24)
Barium meal	110	25	(24)
Barium enema	75	60	(24)
ERCP	220	19.4	(39)
Hysterosalpingography	10	4.1	(39)
Cerebral angiography	50	102	(37)
Coronary angiography	55	36–67	(27,37,40)
Abdominal angiography	90	92	(41)
Renal angiography	160	139–265	(29,37)
Lower limb angiography	90	36	(41)
Cardiac catheterism	122	59	(40)
Stent insertion	84	64	(40)
PTCA	67	90–130	(27,37,42)
Valvuloplasty	149	145	(40)
Angioplasty	14–155	74–108	(40)
Biliary drainage	215	103–184	(37,41)
Pacemaker insertion	38	22	(40)
Abdominal embolisation	478	123	(37)

Table 9. Comparison of DRLs for a few CT Examinations.

Examination	$CTDI_w$ per slice or rotation (mGy)		DLP per examination (mGy cm)	
	This work	Literature[24]	This work	Literature[24]
Head	60	60	800	1050
Sinus	30	35	510	360
Face	30	35	510	360
Chest	15	30	480	650
Abdomen	20	35	710	780
Liver	30	35	1170	900
Pelvis	30	35	540	570

parameters related to the DRLs reported in the literature that would allow a fine comparison of the results, one can assert that in general the two sets of data compare reasonably well, considering the level of variability in the techniques used, particularly in the case of complex examinations.

CONCLUSIONS

The results of the 1998 survey on the exposure of the public by diagnostic and interventional radiology in Switzerland were used to establish diagnostic reference levels for various types of radiological examinations. The average effective doses, calculated by dosimetric modelling using average technical parameters, were multiplied by a factor 1.5 to give results comparable to the DRL data determined by the 3rd-quartile method.

The comparison of the results obtained by this method with those reported in the literature show a satisfactory agreement for most cases, particularly simple examinations. For complex examinations, the discrepancies registered in some cases reflect the various sources of dose variability (how the examination is defined, differences in the techniques and protocols, the complexity of the case and the experience of the radiologist).

The DRLs presented are temporary, until the data collected through dosimetric surveys are available, and a national dosimetric database is set up which will allow the establishment of DRLs based on empirical data, as recommended at the international level.

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