

Diagnostic reference levels for X-ray examinations in Slovenia

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Background. Medical applications of ionizing radiation are by far the largest man-made source of radiation exposure for the population in most developed countries. A good practice in diagnostic radiology should produce an image containing all necessary information needed for accurate diagnosis and should result in the minimum dose to the patient. After introduction of diagnostic reference level by International Commission on Radiological Protection in 1996 the process of patient exposure optimization has been enhanced.

Methods. Local performance in patient exposure for particular type of X-ray examination in radiological department can be assessed by comparison of mean patient dose to the diagnostic reference level derived from relevant regional or national data.

Results. Results of extensive five-year national patient dose survey in Slovenia are reviewed. The proposed Slovenian diagnostic reference levels for fifteen different X-ray examinations are presented, commented and compared with international and national levels of other countries.

Conclusions. The introduction of national diagnostic reference levels will increase the awareness of patient doses in Slovenia. Their proper use should promote good radiological practice by reducing doses where current practice is not optimised.

Key words: radiography; radiation exposure; diagnostic reference level

Introduction

Numerous national and regional surveys have revealed large dose variations for patients undergoing the same type of diagnostic X-ray examination.^{1,2,3,4} The findings have clearly indicated a need for improvements that would lead to patient dose reduction without compromising diagnostic information. The concept of investigation levels for diagnostic medical exposures was first proposed by International Commission

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on Radiological Protection (ICRP) in its 1990 recommendations⁵ and further developed into diagnostic reference level (DRL) in 1996 ICRP Publication 73.⁶ In line with the principle of keeping doses As Low As Reasonably Achievable (ALARA) the European Union member states regulated the optimisation of medical exposures by adoption and implementation of Medical Exposure Directive (MED).⁷ The directive defines DRLs as the dose levels in medical radiodiagnostic practices for typical examinations for groups of standard-sized patients or standard phantoms for broadly defined types of equipment. DRLs are expected not to be exceeded in standard procedures, when good and normal practice regarding diagnostic and technical performance is applied. With this function in mind, the values at which they are set should be at the borderline between the acceptable and the unacceptable current national practice rather than at some optimum level based on the latest and best technology. Although it is known that many aspects of radiodiagnostic practice differ between European Union member states and that these differences may affect the patient dose distributions within each country, it is acceptable to use the levels published by the European Commission when national DRLs are not available. Nevertheless, the regulatory authorities in coordination with the professional bodies of medical radiology and radiological protection, are encouraged to develop guidance and establish DRLs based on their own national dose distributions as soon as feasible. DRLs essentially act as the initial standard in a local radiology audit process for identifying situations where patient doses are unusually high. Local reviews should be undertaken whenever relevant diagnostic reference levels are consistently exceeded and appropriate corrective actions should be taken in order to improve

practice and avoid unnecessary risk due to radiation health effects.

Material and methods

Diagnostic reference levels should be expressed in terms of dose quantities that are well defined and that can be easily measured with sufficient precision and accuracy. A number of different dose quantities can be used, although in practice two are usually applied for routine monitoring of patient doses in conventional radiology. For individual radiograph projections the recommended dose quantities are Entrance Surface Dose (ESD) and Dose-Area Product (DAP).

The Slovenian Radiation Protection Administration and Institute of Occupational Safety started a national patient dose survey in the year 2000.¹⁰ In line with the international recommendations concerning application of appropriate dose quantities, the measurement of the entrance surface dose (ESD) using thermoluminescence dosimeters (TLDs) was chosen. ESD can be directly measured by attaching TLDs to the skin at the point where the centre of the X-ray beam enters the patient. Due to the small size of the TLDs the imaging process is not affected by measurements and there is no loss of diagnostic information on X-ray images. Examples of ESD measurement for three types of X-ray examinations are presented in Figure 1.

Another approach that was also used in the survey is the calculation of patient dose using X-ray examination technical settings and data from X-ray tube output measurements. The relevant parameters and their relation with the ESD are shown in Equation 1.^{12,14} As seen in the equation an appropriate backscatter factor should be applied and the measurement corrected for any differences between the position of the detector and the position of the entrance

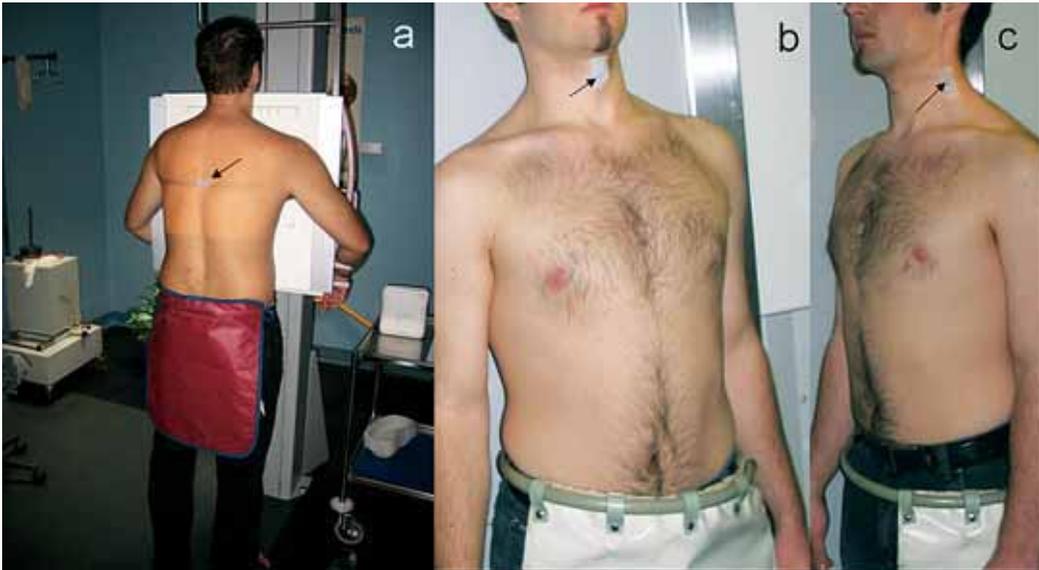


Figure 1. ESD measurement for a) chest examination in PA projection¹⁵, b) cervical spine examination in AP projection and c) cervical spine examination in LAT projection¹⁶. Arrows indicate the TLDs positions.

surface on the patient. Backscatter factors are significant usually ranging from 1.2 to 1.4. for the X-ray spectra and beam sizes used in diagnostic radiology.

$$ESD = \left(\frac{D}{It} \right)_0 \cdot (It) \cdot \left(\frac{FDD}{FPD} \right)^2 \cdot BSF$$

Equation 1. ESD calculation using X-ray tube output and exposure parameters. $(D/It)_0$ is tube output at distance FDD from focus measured at the same tube potential as used for examination, It is product of tube current and exposure time used in the actual examination, FDD is focus detector distance, FPD is focus patient distance and BSF is backscatter factor.

The measurements were carried out with $\text{Li}_2\text{B}_4\text{O}_7$ TLDs. Dosimeters were calibrated with ^{137}Cs gamma rays and their energy responses were corrected to X-ray spectra. It was also found out that the response of TLDs varies less than 10% over radiation energies of X-rays produced at potentials between 50 kV to 120 kV. Since doses are critically dependent on the patient size, measurements were performed on a representative

group of patients with weight close to 70 kg. Taking into consideration only examinations with acceptable image quality, patient related data were collected and radiographic techniques parameters (tube voltage, product of current and exposure time, focus-film distance, screen-film sensitivity and filtration) for each tube and examination type were registered. The mean dose for groups of about 10 patients (for each type of examination performed on a particular X-ray tube) provides a good indication of typical clinical practice in a given institution. Diagnostic reference levels were derived from mean doses for each type of examination performed in different X-ray departments. Diagnostic reference levels should be set with clear understanding of their intended purpose. A pragmatic way of setting diagnostic level for particular examination is to use the rounded third quartile value of mean dose distribution. If 75% of X-ray departments can operate satisfactorily below this dose level, then the remaining 25% should be made aware of their non optimal performance.

Results

By the end of 2005 the Slovenian national patient dose database contained results of over 2000 measurements.^{10,11,12,13} The survey took place at 33 radiological departments, out of which 15 belong to general hospitals and 18 to primary health care centres. Based on frequencies of their use and contribution to the collective dose of the population, the following fifteen examinations were taken into consideration: skull (AP/PA), skull (LAT), cervical spine (AP,LAT), chest (PA, LAT, AP), thoracic spine (AP, LAT), lumbar spine (AP,LAT), lumbo sacral joint (LAT), pelvis (AP), hip (AP) and abdomen (AP). Not all of the listed examination types were assessed in each radiological department, leading to a ground total of 184 analysis performed. It was estimated that measurements were done at institutions performing approximately 25% of all listed diagnostic radiological procedures made in Slovenia. The minimum, mean, 3rd quartile and maximum ESD values for each X-ray examination obtained from distribution of ESD mean values for participating X-ray departments are presented in Table 1.

The proposed Slovenian national reference dose values of ESD per X-ray examination are summarized in Table 2, together with DRLs proposed by IAEA (1994)⁸, EC (1999)⁹, Germany (2002)² and the United Kingdom (2002).⁴ Slovenian DRL values are in general lower than German and higher than United Kingdom values proposed in 2002. At the same time, they are well below the corresponding values proposed by IAEA in 1994 and EC in 1999. Apart from general conclusion one can note that the DRL of chest examination in PA projection and DRL of thoracic spine in LAT projection are slightly higher than the EC recommendations, indicating a non-optimised radiological practice. The DRL of chest examination is higher than the recommended one because in some departments tube voltage settings are lower, while in the others screen-films have lower sensitivity than proposed by the European Guidelines on Quality Criteria for Diagnostic Radiographic Images. The DRL of thoracic spine is higher because tube voltage settings are not adjusted properly according to patient chest thickness.

Table 1. ESD data for fifteen X-ray examination types based on national patient dose survey measurements

X-ray examination	ESD values (mGy)			
	minimum	mean	3 rd quartile	maximum
skull AP/PA	1.15	2.20	2.54	4.19
skull LAT	1.04	1.73	2.02	3.16
cervical spine AP	0.34	1.40	1.73	3.34
cervical spine LAT	0.32	1.40	1.83	3.06
chest PA	0.16	0.29	0.35	0.57
chest LAT	0.40	0.96	1.20	1.93
chest AP	0.15	0.32	0.35	0.60
thoracic spine AP	2.53	5.75	7.69	13.16
thoracic spine LAT	1.98	7.00	10.13	15.30
lumbar spine AP	2.32	6.06	7.98	13.34
lumbar spine LAT	4.91	15.52	19.67	32.28
lumbo sacral joint LAT	4.13	19.75	28.73	40.74
pelvis AP	2.08	4.99	5.83	7.42
hip AP	1.07	3.42	4.94	7.49
abdomen AP	1.73	4.43	6.18	9.96

Table 2. IAEA, EC, German, United Kingdom and proposed Slovenian DRL of ESD per X-ray examination for standard adult patients based on rounded values of the third quartile of the distributions of mean department doses

X-ray examination	ESD values (mGy)				
	IAEA 1994	EC 1999	Germany 2002	U. K. 2002	Slovenia 2005
skull AP/PA	5.0	5.0	5.0	3.0	2.5
skull LAT	3.0	3.0		1.6	2.0
cervical spine AP					1.8
cervical spine LAT					1.9
chest PA	0.4	0.3	0.3	0.2	0.4
chest LAT	1.5	1.5	1.5	1.0	1.2
chest AP					0.3
thoracic spine AP	7.0		7.0	3.5	8.0
thoracic spine LAT	20.0		12.0	10.0	10.0
lumbar spine AP	10.0	10.0	10.0	6.0	8.0
lumbar spine LAT	30.0	30.0	30.0	14.0	20.0
lumbo sacral joint LAT	40.0	40.0		26.0	30.0
pelvis AP	10.0	10.0	10.0	4.0	6.0
hip AP					5.0
abdomen AP	10.0	10.0	10.0	6.0	6.0

More specific information about the national patient dose survey is given in Table 3. In the first column the number of X-ray departments where a particular examination was assessed is given, and in the second column the number of departments where international DRLs were exceeded is listed. The DRL values were in general compared to EU levels, with the exception of thoracic spine where EU⁹ levels were not available and the IAEA⁸ levels were used. For the chest in AP projection and the cervical spine in AP and LAT projections international levels were not available. A review of these data reveals that in about 12% out of 184 examinations analysed the international DRLs were exceeded. The ESD values for the same type of examination in the same X-ray department generally vary due to differences in patient size and in the radiographic technique used by different radiographers. Variations of the mean ESD values for individual X-ray examination between different X-ray departments are also due to differences in radiographic equipment, film type sensitivity, process-

ing chemicals and processing conditions. The range factor is defined as the ratio of maximum to minimum dose for the same type of examination. The range factors of the mean ESD values for X-ray examination types are in the interval from 3 to nearly 10, which is shown in the third column of Table 3. Considering individual measurements instead of department mean values the variations are naturally higher, ranging from 4 to nearly 24 (Table 3 fourth column).

Although the mean ESDs were found to be well below the corresponding European DRLs for most examinations, this does not mean that the dose levels could not be further reduced without loss of diagnostic value by improving the radiographic technique. Considerable dose variations for the same type of X-ray examination strongly support the idea that further optimisation is possible, especially since written examination protocols were found lacking in almost all institutions. The data obtained demonstrate the importance of radiographic staff awareness of regular quality control testing of radiographic equipment.

Table 3. The number of radiological departments where individual examinations were assessed and the international DRLs were exceeded are presented in the first and in the second column respectively. In the third and the fourth column the range factors of mean ESD values from each department, and the range factors of ESD values for individual measurements are summarized respectively

X-ray examination	number of all departments	number of departments with exceeding international DRL	range factor (mean values)	range factor (all data)
skull AP/PA	8	0	3.7	9.9
skull LAT	8	1	3.0	4.4
cervical spine AP	14	-	9.8	13.7
cervical spine LAT	12	-	9.8	12.1
chest PA	23	9	3.7	14.4
chest LAT	17	2	4.9	9.9
chest AP	5	-	4.0	4.0
thoracic spine AP	14	5	5.2	11.8
thoracic spine LAT	11	0	7.7	22.5
lumbar spine AP	17	3	5.8	17.5
lumbar spine LAT	18	1	6.6	23.7
lumbo sacral joint LAT	10	1	9.9	17.8
pelvis AP	10	0	3.7	4.8
hip AP	11	-	7.0	13.3
abdomen AP	6	0	5.8	10.1

Discussion

The patient dose survey was performed in recent years with a goal to get information about the patient doses in common X-ray examinations performed in Slovenia. The data obtained provide a useful base line against which the mean values of patient doses at individual X-ray department may be compared. DRLs are not intended to be applied as investigation levels for individual patients but should be compared with measured or assessed mean values for a representative sample of patients. If the typical dose for a specific type of diagnostic procedure is consistently exceeding the relevant DRL, appropriate corrective action should be taken to improve practice. This could involve changes in procedures or equipment to reduce doses without compromising the quality of the diagnostic information. The radiological department staff should be encouraged to alter their imaging equipment or examination techniques to bring the pa-

tient doses in line with the majority of departments. Periodic monitoring of patient doses and collecting results on a national level are planned to become widespread throughout the Slovenian radiological departments. According to United Kingdom's experience⁴ we expect patient exposure for common conventional X-ray examinations to show a clear trend towards lower doses in a few years. While dose variations for the same type of X-ray examination seems to be more difficult to overcome, a continuing need for bringing radiological procedures in line with European Guidelines on Quality Criteria for Diagnostic Radiographic Images should be emphasized.

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