LOCAL DIAGNOSTIC REFERENCE LEVELS AT THE PORTUGUESE INSTITUTE OF ONCOLOGY FRANCISCO GENTIL OF COIMBRA

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INTRODUCTION

The establishment of internationally accepted radiation protection principles and guidelines comes from the need for protecting people and environment from the pernicious effects of ionizing radiation. The two main objectives are preventing the occurrence of deterministic effects and keeping the probability of incidence of stochastic effects as low as possible.

Based on these aims, the International Commission of Radiation Protection (ICRP) recommends as the three basic principles of radiation protection the justification of the practice, the optimization of protection and the application of dose limits for individual exposures [1].

The first two basic principles are also applied to medical examinations. In fact, every diagnostic exposure should result in a net benefit to the patient. Furthermore, in obtaining the relevant diagnostic information the imaging process should be optimized in order that the patient dose is kept as low as reasonably achievable. The main objective is that the image obtained contains the relevant diagnostic information, so optimization does not just deal with reducing patient doses.

In the context of optimization of radiological exposures, the European Directive 97/43/Euratom, the so Medical Exposure Directive [2], refers the concept of Diagnostic Reference Levels (DRL). They correspond, according to the European Commission definition, to "dose levels in medical radiodiagnostic practices (…) for typical examinations for groups of standard-sized patients or standard phantoms for broadly defined types of equipment". Also stated is that "these levels are expected not to be exceeded for standard procedures when good and normal practice regarding diagnostic and technical performance is applied".[3]

The concept of reference doses levels was introduced in the United Kingdom in the framework of a national survey on radiological practices [4]. Rounded third quartile values for typical adult patients were derived from that questionnaire in the mid-80's. The choice for the third quartile has been made for practical reasons in order to identify 25% of situations requiring urgent inspection.

If the DRLs are systematically exceeded both the procedures and the equipment should deserve inspection in order to adopt corrective actions. Nevertheless the accomplishment of a given DRL does not assure by itself the goodness of the practice. Also, if doses fall substantially below the guidance levels, the image quality may require attention.

In the present work the local DRLs are established for typical radiological examinations carried out in clinical routine at the Oncology Centre of Coimbra, Portugal (IPOFG-CROC, S.A.). The choice of the dosimetric quantity for each kind of radiological examination is discussed. The patient sample corresponds to at least 10 adult patients for each type of examination. The average anterior-posterior (AP) trunk thickness was 20 cm, and the average weight was 70 kg±10 kg (excluding all patient above 90 kg and below 50 kg as recommended in [5]).

In the absence of Portuguese reference dose levels, the obtained values have been compared with the European DRLs [6-9].

METHODS AND MATERIALS

a) Conventional Radiology

For more common and frequent examinations and non-complex procedures the Entrance Surface Dose (ESD), per single view, is one of the recommended quantities that correspond to DRLs [6, 10].

It is expressed as the absorbed dose in air at the point of intersection of the beam axis with the surface of a standard-sized patient, including the backscatter radiation.

In the present work ESD values were assessed through TLD measurements in two radiology rooms where different X-ray units are installed: a Siemens Siregraph C and a Fuji computed radiography equipment FCR 5501 Plus.

The thermoluminescent material used was LiF:Mg,Cu,P, in chips, commercially known as GR200. The TLD automatic reader was a PCL3 and the annealing oven an ETT both from Fimel/PTW. The reference dosimetric system used for TLD dose calibration included a 6cc ionization chamber, model 10X9-6, and a control unit model 9095 from Radcal.

The readout cycle, including preheating and heating cycles, has been established after an optimization study on the reproducibility of the dosimeters where a group of 35 TLDs, divided in five sets of seven dosimeters were exposed in a reproducible setup and irradiation conditions and where different preheating temperatures have been used for each dosimeter set. The irradiation was repeated six times for each set, using the same annealing cycle after each exposure. Also the annealing cycle has been optimized, through the inspection of the glow curves after different annealing temperatures. The optimal cycle corresponded to 245ºC during 15 minutes.

The lower group standard deviation was obtained for a preheating cycle at 155ºC during 35 s, followed by a heating cycle at 260ºC during the same time. The mean standard deviation corresponded to 4,1%.

After this optimization study on the readout cycle, the individual reproducibility of the dosimeters was assessed through the irradiation of 30 dosimeters, 7 times in the same conditions. After the exclusion of 2

dosimeters that have presented a poor reproducibility with standard deviations above 5%, a group of 28 TLDs has been used for patient measurements with response variations around the mean of less than 3,9%.

ESD values have been obtained for different radiological examinations. For each exposure, two TLDs (each with a thin Mylar protection envelope) were placed on the patient skin at the intersection of the beam axis.

At least 10 patients were chosen for each type of examination. Along with the TL dosimeters used for dose assessment also a control group of dosimeters have accompanied all procedures except radiation exposure in order to obtain a background correction factor.
The entrance surface dose values that can be compared with the European DRL for each type of examination have been obtained through the average over the patient sample, of the values obtained for each patient:

$$\mathrm{ESD}_{\mathrm{patient}} = \overline{\mathrm{TL} * \mathrm{Fcal}} \qquad \textit{(mGy)}$$

where the average corresponds to both TLDs placed on the patient skin, TL is the readout of each dosimeter, corrected from background and F_{cal} its dose calibration factor.

b) Computed Tomography

For CT examinations the basic recommended dosimetric quantity is the Computed Tomography Dose Index (CTDI) which is defined as the integral of the dose profile along the rotational axis for a single axial slice, divided by the nominal slice thickness.

Different descriptors are defined to serve the aim of referring radiation dose due to CT examinations, namely $CTDI_{100}$, $CTDI_w$ and DLP (Dose Length Product describes complete examinations). $CTDI_w$ and DLP both relate to measurements in standard phantoms and represent quantities for assessment of performance of the equipment and the technique used in CT [7,11,12]. $CTDI_w$ can be measured directly or obtained from $CTDI_{100}$ (measured in air) using some phantom factors (P_H for head/neck and P_B for body).

In the present work $CTDI_w$ values have been measured in standard PMMA phantoms for head and body, for a HiSpeed LX/i CT unit from GE, with a pencil ionization chamber with an active length of 100 mm and a sensitive volume of 3,14 cc (model 30009 from PTW, Freiburg) associated with a DIADOS electrometer also from PTW.

In order to obtain P_H and P_B phantom factors referred above, also $CTDI_{100}$ has been measured.

Reference exposure settings have been established corresponding to exposure time of 1s, slice thickness of 10 mm, 120 kV and 150 mA. $CTDI_{100}$ values for reference conditions have been compared with varying exposure parameters like – mA, kV, time, slice thickness (h), pitch and

Scan Field of View (SFOV). $CTDI_w$ depends quadractically on tube voltage and linearly with current and exposure time. It is independent from slice thickness (above 3mm) and from pitch.

The patient sample involved 133 adult patients of both sexes. The type of examinations included: head, neck, chest, abdomen and pelvis. All exposure parameters have been collected and the corresponding $CTDI_w$ and DLP values have been determined. The average values for each type of examination were compared with the European DRLs [7].

The $CTDI_w$ corresponding to each exposure conditions (kV,mA,s,h) was determined through the following equation:

$$CTDI_W(kV, mA, s, h) = CTDI_{100}(kV', mA', s', h') \cdot P_{H/B}(kV) \cdot f(kV) \cdot f(mA) \cdot f(s) \cdot f(h)$$

where $CTDI_{100}$(kV',mA',s',h') corresponds to $CTDI_{100}$ measured in air for reference conditions and each correction factor f(i) corresponds to the normalization of the ith exposure parameter from actual exposure settings to the corresponding reference value.

c) Mamography

The Average Glandular Dose (AGD) is defined as the average dose over the glandular tissue (excluding the skin) for a uniformly compressed breast and it is an appropriate breast cancer risk predictor. AGD cannot be measured directly and it is usually calculated from the Entrance Surface Air Kerma (ESAK) or from ESD using adequate conversion factors as a function of measured half-value layer (HVL). This can be determined either for a standard phantom or for a representative selection of patients. European DRLs for mammography are expressed directly in ESD [6,8].

The use of different tube voltages for different breasts thicknesses and different programmable exposure modes (including target material) requires a large number of measurements on various combinations of tube voltage, target and filtration.

Before starting patient dose assessment, also accuracy and precision of tube voltage should be checked together with HVL evaluation for the beam quality used in clinical practice.

The tube voltage accuracy and precision were determined through repeated exposures with the same tube settings, using a proper voltage sensor (model 40X9-Mo from Radcal). The tolerances accepted for accuracy and precision were ±0,5 kV and ±1 kV, respectively, according to quality assurance recommendations [13].

HVLs for the various combinations anode/filtration were determined according to the recommended geometrical setup [8], through the interposition of increasing high purity (99,99%) aluminium layers of different nominal thicknesses.

ESAK measurements have been performed with a 6 cc ionization chamber (model Radcal 10X5-6M) with associated electrometer Radcal 9095, in a mammography unit Siemens Mammomat 3000.

For each combination anode/filtration, the exposure reference conditions have been established in terms of kV and mAs. The evaluation of the ESAK variation with each of the exposure parameters was done for each anode/filtration pair.

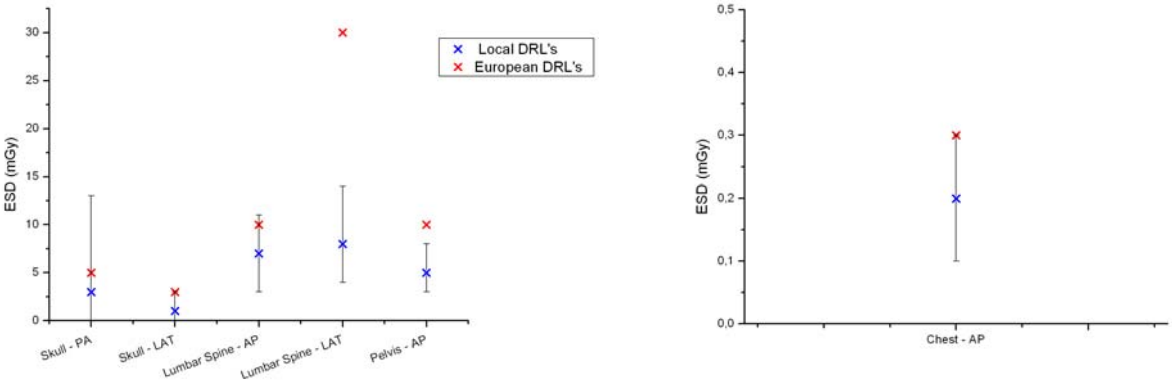
The patient sample involved 148 women who realized mammography in both incidences – cranio-caudal and oblique. ESAK values have been determined through the reference exposure value for the corresponding anode/filtration used in each case, corrected by a factor corresponding to the actual exposure parameters. ESDs to be compared with European DRLs were obtained using a backscatter factor of 1,09 [8].

RESULTS AND DISCUSSION

a) Conventional Radiology

Local Diagnostic Reference Levels (LDRLs) for common examinations in conventional radiology are presented in Fig. 1 for both X-ray units installed in the Radiology Department. They are compared with the corresponding European DRLs. As stated before LDRLs correspond to the average of the ESD values obtained for the patient sample in each type of examination. Also shown in the figure are the minimum and maximum ESD values obtained for each kind of exposure.

The resume of the results for the different types of radiological exposures, that included - skull posterior-anterior (PA); skull-lateral (LAT); lumbar spine anterior-posterior (AP); lumbar spine-LAT; pelvis-AP (room 1) and chest AP (room 2) - is presented in Table I.



(a) *(b)*

Fig. 1 - Local Diagnostic Reference Levels compared with the corresponding European DRLs for conventional radiology examinations performed in a) Room 1 (Siemens Siregraph C X-ray unit) and b) Room 2 (Fuji FCR 5501 Plus X-ray unit)

Exams	LDRLs(min-max) (mGy)	European DRLs (mGy)
Skull-PA	3,3 (0,1-13,4)	5
Skull-LAT	1,5 (1-2,7)	3
Lumbar Spine-AP	6,7 (3,2-10,9)	10
Lumbar Spine-LAT	7,6 (3,7-13,7)	30
Pelvis-AP	5,1 (2,8-8,4)	10
Chest-AP	0,2 (0,1-0,3)	0,3

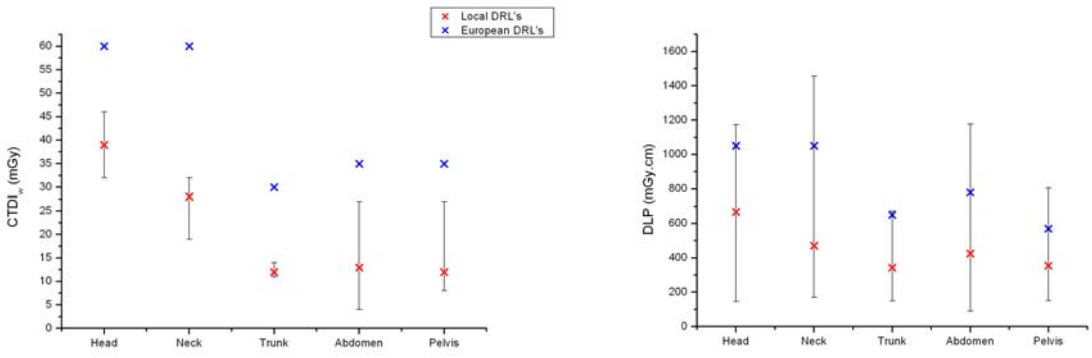
Table I - Local Diagnostic Reference Levels compared with the corresponding European DRLs for conventional radiology examinations.

We can see that LDRLs are always below the European DRL. Nevertheless we cannot say that in every examination the standard was met, namely for skull PA exposures. However, there is some type of examinations like lumbar spine in lateral exposure where all measured entrance surface doses were well below the corresponding reference level.

b) Computed Tomography

For CT examinations the exposure settings are chosen through predefined clinical protocols in the scanner software. They are named according to each clinical situation - head, neck, trunk, abdomen and pelvis.

The evaluated $CTDI_w$ values for each clinical protocol are presented in Fig. 2. For the 133 adult patient sample used also DLPs for each examination were calculated. Both dose descriptors are compared with the corresponding European DRLs, in Fig. 2 a) and b).



(a) *(b)*

Fig. 2 – Local Diagnostic Reference Levels – a) $CTDI_w$ and b) DLP - compared with the corresponding European DRLs for clinical protocols used in CT examinations

In Table II the numerical values are shown including maximum and minimum values determined for each clinical protocol.

As it is clearly seen in Fig. 2a), all measured $CTDI_w$ values (which is an index that corresponds to single slice examination) are below the reference level whereas DLP values, that refer to actual complete examinations show a larger variation and also some situations where the reference level is exceeded.

Exams	LDRLs(min-max) (mGy)				European DRLs (mGy.cm)	
	$CTDI_w$		DLP		$CTDI_w$	DLP
Head	39	(32,4-45,6)	668	(146-1174)	60	1050
Neck	27,9	(18,7-30,4)	472	(171-1457)	60	1050
Chest	12,3	(10,6-14,2)	343	(149-672)	30	650
Addomen	12,7	(4,5-26,6)	425	(92-1177)	35	780
Pelvis	11,9	(8,2-26,6)	354	(151-806)	35	570

Table II – Local Diagnostic Reference Levels ($CTDI_w$ and DLP) compared with the corresponding European DRLs for for clinical protocols in CT examinations.

c) Mammography

The importance of checking both tube voltage and HVL in mammography was already stated. In Tables III and IV the results obtained for the combinations anode/filtration used in clinical practice are presented.

Nominal Tube voltage (kV)	Measured Tube voltage (kV)
Mo/Mo	
26	26 (± 0,11)
27	27 (± 0,08)
28	28,1 (± 0,12)
29	29,4 (± 0,16)
Mo/Rh	
27	27,3 (± 0,13)
28	27,6 (± 0,09)
30	29,4 (± 0,46)
W/Rh	
31	29,7 (± 0,26)

Table III – Nominal and measured values of tube voltage for the anode/filtration pairs used in clinical examinations.

Combination Anode/Filtration	***Tube voltage (kV)***	***HVLmeasured (mm Al)***	***HVLref (mm Al)***
Mo + 30 μm Mo	26	0,37	0,359
	27	0,39	0,371
	28	0,4	0,38
	29	0,41	0,39
Mo + 25 μm Rh	27	0,44	0,422
	28	0,45	0,433
	29	0,46	0,446
	30	0,47	0,455
W + 50 μm Rh	31	0,59	0,581

Table IV – Measured values of HVL for the different beam qualities used in clinical practice compared with HVL_{ref} which correspond to typical HVL values as referred in the European protocol on dosimetry in mammography [8].

To compare with the European DRLs in mammography the calculated ESDs that correspond to our local reference levels are presented in Fig. 3

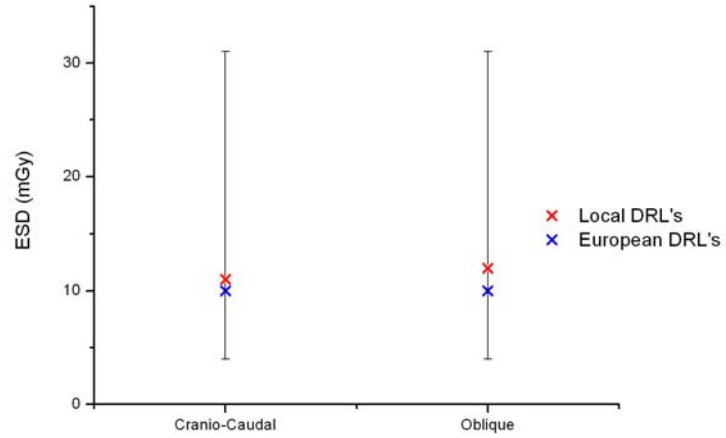


Fig. 3 – Local Diagnostic Reference Levels in mammography compared with the corresponding European DRLs.

The results clearly show that the majority of ESD values determined in mammography exceed the recommended reference level, despite the fact that averages do not differ from them more than 10%.

CONCLUSIONS

In the scope of medical radiological exposures and according to European recommendations and national legal requirements [14], the maximum responsible for an installation must assure the establishment of local dose levels for each type of radiological examination and also assure that they are available for the doctor who prescribes the examination. In the absence of national reference dose levels, the so called Local Diagnostic Reference Levels should be in agreement with the European Diagnostic Reference Levels published for the different types of medical exposures.

The aim of this work was to establish a protocol of measurement for each type of more frequent examination, namely in conventional radiology, in CT and in mammography performed in our hospital.

For each kind of examination the recommended dose descriptor was adopted and directly measured or derived from basic charge measurements.

The patient sample corresponded in each case to at least a minimum of 10 standard-sized patients, as recommended, in order to obtain averages that constitute for each type of radiological examination the LDRLs that could be compared with the European DRLs.

The results obtained are in the large majority of the situations below the corresponding DRL. Nevertheless we have identified some situations that deserve more attention.

In conventional radiology all LDRL are below the reference levels. However we have detected some skull PA exposures where entrance skin doses exceeded the standard value. This may be due to equipment age problems but, as always, improvement of staff education will contribute to better practices and we hope that this work can contribute to this objective.

In CT the LDRL that corresponds to single slice scan meet the standards whereas complete examinations described by DLP values show a larger variation and also some situations where the reference level is exceeded. It is possible that doctors are requiring too large ranges for complete examinations.

Mammography was perhaps the area that deserved more evident alert. The results clearly showed that the majority of ESD values determined in mammography exceeded the recommended reference level. In fact the mammography unit used to establish the dose measurement protocol was dismounted soon after the end of this work. A new digital mammography unit is now installed. We hope that new LDRL that will soon be obtained can accomplish the dose requirements.

The results obtained so far may not be the best ones but it was the beginning of a very important way towards better practices, more information to staff and patients and improved quality assurance of clinical radiological examinations.

As a last conclusion we would like to state that this was a pioneer work in Portugal. We hope that this may lead the way to further developments.

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