European Medical ALARA Network

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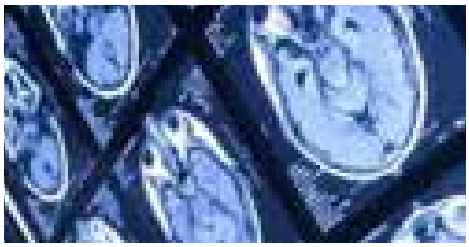
TABLE OF CONTENTS



This is the 3rd newsletter of the European Medical ALARA Network (EMAN) in which 3 professional organisations are involved as steering partners – the European Society of Radiology (ESR), the European Federation of Radiographer Societies (EFRS) and the European Federation of Organisations for Medical Physics (EFOMP). Each newsletter focuses on one topic, and the members of the EC-funded EMAN project are invited to contribute articles.

The particular newsletter in your hands is dedicated to the EMAN Working Group 1 (WG1) that was focussed on the "Optimisation of Patient Exposure in CT Procedures". This CT task group included representatives of relevant scientific bodies, such as the European Radiation Dosimetry Group (EURADOS), EFOMP, EFRS and ESR, as well as well-known experts in the field of CT technology, risk assessment and medical exposures.

The highlights of this issue include the reports of members of the group on the need to clearly indentify clinical benefit from the increasing use of CT versus the associated radiation risks, on the development and implementation of harmonized referral guidelines on a European level, on the need to implement CT-DRLs in more European countries and to revise CT-DRLs in adults and to evaluate CT-DRLs in children and young adults as well as for new techniques such as cardiac or perfusion CT and finally on the necessity to form a radiological "core team" . This team should include a radiographer, a radiologist and a medical physicist for each CT facility, being responsible for optimization of CT scanning protocols, supervision of the use of scanning protocols, and training of CT staff.

We hope you will enjoy reading this latest EMAN newsletter and find the articles informative.

The EMAN Steering Committee

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CT Medical Exposures and CT Risk/Benefit Estimation

CT MEDICAL EXPOSURES

In Article 12 of the Medical Exposure Directive of 1997 [1], entitled "Estimates of Population Doses", the European Commission requires Member States to 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. As a consequence, in various countries in Europe, surveys were launched focussing on both the total collective effective dose and the collective effective dose of various types of X-ray examinations. The results available raised awareness that medical exposures are by far the largest source of man-made population exposures to ionizing radiation and that CT is the major contributor followed by angiographic and interventional procedures. According to UNSCEAR, CT accounts for 42% of the total collective effective dose due to medical diagnostic exposure in 1997 to 2007 [2].

International reviews, e. g. the UNSCEAR report [2], as well as recent publications from several countries, e.g. Switzerland, Germany, and UK, reveal the steadily increasing impact of CT on medical exposures over the last decade, resulting in steadily increasing total effective doses due to diagnostic imaging. It is interesting to note that this trend is accompanied by a decrease in the frequency of conventional X-ray examinations (apart from angiography and interventional procedures). It may be speculated that low dose imaging techniques such as conventional X-ray examinations are – at least in part – steadily being replaced by high dose CT examinations, resulting in the observed increase of medical exposures.

In line with this kind of reasoning, it has to be considered that the clinical impact of CT in many cases outweighs the diagnostic value of conventional X-ray examinations. Unfortunately, the available data are insufficient to investigate this issue. In particular, a thorough analysis weighing the clinical benefit from the increasing use of CT

against the resulting radiation risks would require detailed information of both the age of the patients and the clinical indication of the performed CT examinations. Apart from a few exceptions, such as Denmark with its centralised healthcare system, such data are hardly available at present. Nevertheless, this kind of study would be important in order to adequately evaluate the increasing impact of CT on medical exposures.

In addition, there is a strong correlation between the number of CT devices and the CT examination frequency. It may be speculated that the reimbursement system – in particular in countries such as Germany or the USA with a high percentage of private practices ("pay per exam") – has a certain impact on both the number of CT devices and the number of CT examinations.

CT RISK / BENEFIT ESTIMATION

Tremendous developments in CT technology have taken place over the last decade. The growing use of radiation related to this technology is of great benefit to individual patients and to society as a whole. However, radiological imaging always poses some risk of adverse health effects to the person examined – in particular radiation-induced cancer. Although individual risk estimates for single examinations are small, there might be concern over radiation risks due to the currently increasing radiation exposure resulting from X-ray diagnostics, especially from CT, since small individual risks applied to an increasingly large population may result in a potential public health issue some years in the future.

Besides, some CT examinations such as whole-body CT deliver in one single examination the dose to a patient that may exceed the dose limit of 20 mSv per year for an occupationally exposed worker. In addition, organ doses – in particular in repeated CT scanning – may reach values beyond 50 to 100 mGy. Concerning dynamic contrast-enhanced CT examinations, even higher organ doses may occur. Scientific evidence is sufficient to conclude a statistically significant increase of cancer rates attributable to radiation exposures in this dose range.

To justify CT examinations, it is pivotal to critically weigh the benefits of CT against the individual detriment. It is important to note that the principle of justification is at least as important as the principle of optimization in order to ensure radiation protection in medicine. Unfortunately, the actions initiated by international radiation protection organizations and national regulators often show a tendency to suggest separate approaches to develop and consolidate both fundamental principles in medicine – with emphasis on medical and radiological practitioners concerning justification and with emphasis on technical staff and medical physicists concerning optimization. However, in clinical practice, a close interaction of both principles is strongly needed. Even an optimised application of X-rays fails to comply with the principles of radiation protection in medicine, if it is not justified. As a consequence, it should be considered to extend the ALARA approach by launching concerted actions taking both principles into account.

Healthcare

In the past, health strategies focused on a patient with recognized symptoms presenting to a medical doctor in a hospital or private practice. If the medical doctor needs further diagnostic information, he or she refers the patient to a radiologist performing the adequate X-ray exam. This scenario is usually denoted as healthcare.

Concerning healthcare, evolving new X-ray technologies such as multi-slice spiral CT have a rapidly growing impact on the treatment of patients. Hereby, it has to be considered that only a small fraction of the population receives medical exposures in any year, in particular elderly and severely-ill persons, who may hopefully benefit from these new X-ray technologies. With respect to risk, it is important to note that life-expectancy may be shorter than the latency period for radiation-induced cancer for a significant fraction of patients undergoing CT, and that radiation-induced cancer risk is usually outweighed by benefit for those surviving the latency period – provided an adequate justification has been carried out. Nevertheless, in order to obtain sufficient scientific evidence, a reliable benefit-risk analysis of radiological imaging procedures has to be broken down to diagnosis-related groups of patients, in particular to those being highly exposed as well as to those being particularly radio-sensitive, especially children and young adults.

Individual health assessment

With the rapid development in multi-slice spiral CT, which offers the potential to scan large parts of the body within only a few seconds, a new emerging scenario has to be considered: individual health assessment, also denoted as opportunistic screening.

Screening is a significant departure from the conventional clinical model of care, because apparently healthy individuals are offered a test. An effective screening either detects risk factors for developing a disease or it detects the disease itself at an early stage where treatment can improve clinical outcome. The aim is to identify those individuals who are more likely to be helped than harmed by further diagnostic tests or treatment [3].

At present, predominantly the following CT procedures are discussed for screening:

- lung CT for early detection of lung cancer, in particular in heavy smokers and asbestos workers;
- virtual CT colonoscopy – also denoted as CT colonography – for early detection of intestinal polyps (which might be pre-cancerous lesions) and colorectal cancer;
- CT quantification of coronary artery calcification (which is considered as sensitive marker of arteriosclerosis);
- whole-body CT, particularly for early detection of cancer.

Due to the typically low prevalence of serious diseases in an asymptomatic population, the vast majority of individuals undergoing screening are not affected by the disease. These individuals do not derive a direct health effect, but can only be harmed either by radiation induced cancer or by adverse health effects such as false-positive results and overdiagnosis. With respect to benefit, it has to be kept in mind that, in contrast to X-ray mammography, only a few valid data from prospective, randomized clinical studies – and only in case of lung cancer screening [4] – are yet available, indicating a significant reduction in cancer mortality due to CT screening. Nevertheless, national guidelines of scientific bodies in particular in UK und USA conclude that there are sufficient data to include some CT procedures as an acceptable option for cancer screening. E.g., in July 2013, the U.S. Preventive

Services Task Force (USPSTF) issued a draft recommendation (grade B) in favour of CT lung cancer screening for long-term smokers making CT an accepted screening test for lung cancer, comparable with mammography in case of breast cancer screening [5]. This draft recommendation is also supported by the American College of Radiology (ACR).

When considering scientific evidence being sufficient, it is pivotal to claim that the respective individual health assessment by CT is embedded in a well-established screening algorithm and is properly quality assured along the whole screening chain. I.e., standardised and optimised protocols and algorithms must be available concerning the definition of risk profiles, technical performance of CT, reading and diagnostic workup of suspicious findings, training and education as well as documentation and evaluation. It has to be highly recommended to initiate actions on national and international level addressing these important issues. From the radiation protection perspective, these issues were treated in some more detail in a HERCA "Position Paper on Screening" in the framework of the exposure of asymptomatic individuals in healthcare [6]. The position paper proposes a clear distinction between screening and radiological procedures as part of an individual health assessment and highlights special requirements for the latter.

It is important to distinguish opportunistic screening from organized screening programmes. Organized screening programmes systematically invite all members of a certain well-defined population to take a screening test. For example, several breast screening programmes in Europe were established. These programmes are evidence based and meet stringent quality requirements [7]. At present, no CT based organized screening programmes have been launched.

Up to now, CT based individual health assessment may not play a dominant role in medical exposures in Europe. However, this could change dramatically within the next few years, if opportunistic CT screening is extensively advertised by providers and – as a consequence – is widely accepted by the public. This kind of advertisement must be critically questioned as long as there is lack of evidence in supporting the screening procedures on offer, since asymptomatic individuals are potentially put at risk while the benefit is vague. This is especially the case as the service is unlikely to be properly quality assured or coordinated. Furthermore, in an opportunistic screening, individuals are unlikely to receive sufficient information to enable them to make an informed decision as to whether or not to undertake the screening test.

In summary, in both scenarios – healthcare and individual health assessment – it is pivotal to weigh the total potential diagnostic or therapeutic benefits of CT against the individual detriment, providing the base for the appropriate justification of CT scanning. Hereby, it is worth noting that the application of ionising radiation in both healthcare and individual health assessment, requires an individual justification, while officially approved screening programmes are justified generically.

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CT Dose Reporting

INTRODUCTION

CT examinations represent relatively high patient radiation exposures to an increasing number of patients. The Directive 97/43/EURATOM formalised, from the legal point of view, the need for practical CT dosimetry in Europe [EC 1997]. It required that CT scanners provide an indication of patient dose and that users implement quality assurance programmes, which should include patient dose assessment. These requirements are included and reinforced in the proposal for a new Council Directive laying down basic safety standards for protection against the dangers from exposure to ionising radiation, which is expected to be approved by October 2013 [EC 2012].

Because of the inherent complexity of the CT technique, specific dosimetric quantities had to be defined in the early eighties [Shope 1981]. Different quantities are available to assess the radiation exposure due to CT examinations, but very often there are some misunderstandings and some quantities are not used properly.

In the following paragraphs the basic quantities shall be defined, emphasising their use and limitations.

CT DOSE QUANTITIES

The current procedure for reporting radiation dose in computed tomography is based on the use of *the computed tomography dose index (CTDI)* introduced by Shope et al in 1981 [Shope 1981], together with the use of *dose-length product (DLP)* [EC 2000; ICRP 2007a]. However, neither the CTDI nor the DLP of a scan represent the patient dose [McCollough 2011]. Specific corrections for patient size and age, but also for beam width or stationary patients might be required [Boone 2007; AAPM 2008].

The *CTDI*, integrates the radiation dose imparted within and beyond a single slice and it is defined by the following equation:

$$CTDI = \frac{1}{T}\int_{-\infty}^{+\infty} D(z)dz \qquad (1)$$

Where, T is the nominal slice thickness and D(z) is the dose profile along a line parallel to the z-axis (tube rotation axis).

The CTDI can be measured in air or in a phantom and this is usually indicated with a subscript, i.e. $CTDI_{air}$. . The CTDI value provides information about the characteristics of the radiation beam, filtration, collimation, etc.

In practice, dose profiles are measured in a defined length. In Europe, the EC Guidelines [EC 2000] propose an integration range over a length of 100 mm positioned symmetrically about the scanned volume. $CTDI_{100}$ notation is used in this case. The use of $CTDI_{100}$ was eventually standardized by the International Electrotechnical Commission [IEC 2002] and has been adopted by CT manufacturers and regulatory authorities internationally.

For CTDI measurement in phantom, two polymethylmethacrylate (PMMA) cylinders of 14 cm length are used. For head examinations, a phantom diameter of 16 cm is used and for body, a phantom diameter of 32 cm is applied. The phantoms are called, respectively, *head and body CTDI phantoms*. CTDI is usually measured using a specially designed "pencil" ionization chamber with an active length of 100 mm both in free air at the centre of rotation ($CTDI_{air}$) and within the holes of the 2 phantoms. $CTDI_c$ and $CTDI_p$ are defined respectively as the CTDI values measured with a pencil chamber dosemeter positioned in the centre and in the periphery of the PMMA head or body phantom.

$CTDI_w$ is used for approximating the average dose over a single slice in order to account for variations in dose values between the center and the periphery of the slice. It is defined by the following equation:

$$CTDI_w = \frac{1}{3}CTDI_c + \frac{2}{3}CTDI_p \qquad (2)$$

Where: $CTDI_p$ is the average of four $CTDI_p$ values measured in the periphery of the phantom (12, 3, 6 and 9 o' clock).

$CTDI_{vol}$ [IEC 2003], initially also called CTDIw,eff, represents the radiation dose in one tube rotation in multiple detector CT (MDCT) and allows for variations in exposure in the z direction when the pitch (p) is not equal to 1.

The pitch for a scan sequence is the ratio of the table feed in one rotation (I) to the product of the nominal section thickness (T) and the number (N) slice of simultaneous tomographic sections from a single rotation. The product (NT) corresponds to the slice collimation.

$$CTDI_{vol} = \frac{NT}{I}CTDI_w \qquad (3)$$

$$CTDI_{vol} = \frac{CTDI_w}{p} \qquad (4)$$

Equation (4) applies when p is not equal to 1.

The subscript, *n*, $_nCTDI$, is sometimes used to denote when measurements of CTDI have been normalized to unit radiographic exposure (mAs), it is expressed in terms on mGy/mAs.

$CTDI_w$ or $CTDI_{vol}$, are measured in mGy. CTDIvol display on the CT console is required for all new scanners [IEC 2002; EC, 1997].

The interpretation of dose values displayed on the scanner's console needs special attention in some situations, such as when the pitch is not 1. Many dose recommendations are expressed in $CTDI_w$, whereas the CT console displays $CTDI_{vol}$. In order to allow comparisons, the pitch correction involved in $CTDI_{vol}$ should be reverted by multiplying $CTDI_{vol}$ by the pitch factor.

The DLP is used to calculate the dose for a series of slices or a complete examination and is defined by the following equation:

$$DLP = \sum_i {}_nCTDI_w \cdot T \cdot N \cdot C \qquad (5)$$

Where i represents each one of the individual series forming part of an examination, N is the number of slices in serie i, each of thickness T (cm) and C (mAs) is the radiographic exposure, in serie i.

In the case of helical scanning:

$$DLP = \sum_i {}_nCTDI_w \cdot T \cdot A \cdot t \qquad (6)$$

Where, for each of i helical sequences forming part of an examination, T is the nominal irradiated slice thickness (cm), A is the tube current (mA) and t is the total acquisition time (s) for the sequence. nCTDIw is determined for a single slice as in serial scanning.

DLP is measured in terms of mGy.cm. It is an indicator of the total radiation dose given to the patient during a specific examination or series of slices, whereas, CTDI is by definition an indicator of the level of local "dose" in the irradiated slice. This practically means that for a given technical protocol with certain CTDIvol, the DLP of 2 scanning regions with different lengths will be different. Many new scanners show DLP values on the CT console.

Although CT scanner consoles and most international recommendations, in particular EC guidelines [EC 2000] and IEC standards [IEC 2003; IEC 2009], use the terms CTDI and DLP, in 2005, the International Commission on Radiation Units and Measurements (ICRU) proposed a new nomenclature to refer to CT dose quantities [ICRU 2005]. ICRU Report 74 recommends the use of the quantity CT air kerma index (C_{KL}) instead of CT dose index (CTDI), and air kerma-length product (P_{KL}) instead of dose-length product (DRL). ICRU considers the use of the term air kerma to be more appropriate than *absorbed dose or dose*. For diagnostic X-ray energies, the absorbed dose and the kerma in the same material are numerically equivalent, thus, the new recommendations of ICRU would practically not imply any changes in measurements, but it introduces some confusion in an already complex topic. The International Atomic Energy Agency (IAEA) in the Technical Reports Series No. 457 *"Dosimetry in diagnostic radiology: an International Code of Practice"* [IAEA 2007] follows the recommendations and notations given in ICRU 74 for CT dose quantities.

CTDI limitations

The definition of CTDI and of the standard phantoms to measure it was a crucial milestone in quantifying the radiation output of a CT scanner consistently and reproducibly. However, CTDI has several limitations, which have been reported by several authors.

Since the introduction of *CTDI* there have been important advances and changes in CT technology, as well as an increase of operation modes and applications of CTs [Wang 2008]. CTDI was initially defined for axial scanning. Its application for helical and cone-beam CT systems has some limitations [Brenner 2005; Dixon 2006; Boone 2007]. Several groups are working on proposing alternative quantities [Dixon 2003; Mori 2005; IEC 2010].

$CTDI_{100}$ measurement requires integration of the radiation dose profile from a single axial scan over ±50 mm, usually performed with a 100 mm-long, 3 cm3 active volume "pencil" ionisation chamber. For narrow scan slices, up to 40 mm, it is a good estimate of the average absorbed dose, along the z-axis, from a series of contiguous irradiations. However, for slice collimations greater than 100 mm, such as those of 256 or 320 CT scanners, $CTDI_{100}$ underestimates the absorbed dose.

The American Association of Physicists in Medicine proposes in Report n°111, *Comprehensive methodology for the evaluation of radiation dose in X-ray computed tomography* [AAPM 2010], a new measurement paradigm based on a unified theory for axial, helical, fan-beam and cone-beam scanning with or without longitudinal translation of the patient table [Dixon 2003]. The report is very recent and some practical questions, such as the type of phantom, are not clearly yet.

IEC proposes an alternative approach retaining the standard CTDIvol with some corrections for nominal beam widths larger than 40 mm [IEC 2010]. This proposal is for the moment recommended by the International Atomic Energy Agency for wide cone beam scanners [IAEA 2011]. An internationally agreed proposal in this field would be desirable. Depending on the chosen alternative, it can involve major changes in the selection of instruments, phantoms or procedures.

In spite of the above mentioned limitations of CTDI measurements, $CTDI_{vol}$ is a useful index to compare scan protocols and scanners, however they cannot be used as a measurement of patient dose. Mc. Collough [McCollough 2011] illustrates very clearly the difference of concepts and prevents about the widespread misinterpretation of considering CTDI a measure of patient dose.

RELEVANT RISK-RELATED QUANTITIES FOR MEDICAL EXPOSURE OF PATIENTS

The *effective dose*, E, has long being used as a useful quantity to assess the potential radiological risk of a patient [Fujii 2009; Gregory 2008; Cohnen 2003]. It is defined in ICRP 60 [ICRP, 1991] and ICRP 103 [ICRP 2007b], as the sum over all the organs and tissues of the body of the product of the equivalent dose, H_T, to the organ or tissue and a tissue weighting factor, w_T, for that organ or tissue.

$$E = \Sigma_T w_T H_T \quad (7)$$

The tissue weighting factor, w_T, for organ or tissue T represents the relative contribution of that organ or tissue to the total detriment arising from stochastic effects for uniform irradiation of the whole body. The unit of effective dose is the sievert (Sv). The sum over all the organs and tissues of the body of the tissue weighting factors, w_T, is unity.

Since, effective dose is not measurable, a 'conversion coefficient' relating it to $CTDI_W$ or DLP is needed. The EC guidelines [EC 2000] provided a series of normalised values of effective dose per dose-length product over various body regions for a broad estimate of effective dose. However, effective dose calculation is based on a "hermaphrodite standard human body" and can thus imply large differences with specific individual patient doses.

Monte Carlo calculations for CT have been carried out to supplement the relative lack of normalised organ dose data available for paediatric patients. Shrimpton [Shrimpton 2004] in report NRPB-PE/1/2004 presented a new series of coefficients for newborn, 1 year old, 5 year old, 10 year old, 15 year old and adult. Shrimpton's coefficients were also published as appendix C of the 2004 *European Guidelines for Multislice Computed Tomography* [Bongartz 2004]. These results confirm the trends for an enhancement of the doses to small children relative to those to adults under similar conditions of CT exposure. More recently, the AAPM report n°96 [AAPM 2008], also adopted the same values of normalised effective dose per dose-length for various ages.

Another aspect to be considered when using conversion coefficients for children is that one ▸

must be aware that these coefficients have been obtained for a 16 cm CT dose phantom, whereas the CT console indicator might provide DLP or CTDIw assuming the use of the 32-cm diameter body phantom.

As stated in ICRP Publication 103, articles 151 and 152 [ICRP 2007b], *"The relevant quantity for planning the exposure of patients and risk-benefit assessments is the equivalent dose or the absorbed dose to irradiated tissues. The use of effective dose for assessing the exposure of patients has severe limitations that must be considered when quantifying medical exposure. Effective dose can be of value for comparing doses from different diagnostic procedures and for comparing the use of similar technologies and procedures in different hospitals and countries as well as the use of different technologies for the same medical examination. However, for planning the exposure of patients and risk-benefit assessments, the equivalent dose or the absorbed dose to irradiated tissues is the relevant quantity". "The assessment and interpretation of effective dose from medical exposure of patients is very problematic when organs and tissues receive only partial exposure or a very heterogeneous exposure which is the case of CT"*.

The *mean absorbed dose in a specified tissue or organ*, often referred to as *organ dose*, D_T, is the preferred quantity to estimate CT risk [Brenner 2007].

D_T is the mean absorbed dose in a specified tissue or organ and it is equal to the ratio of the energy imparted ?, to the tissue or organ to the mass, m_T, of the tissue or organ, [ICRU 51].

8 $$D_T = \frac{\overline{\varepsilon_T}}{m_T}$$

The unit of absorbed dose is the gray (Gy).

A more precise procedure to estimate the organ dose and the effective dose, is by using several available software, such as CT-Expo [Stamm and Nagel 2002] and ImPACT CT Patient Dosimetry Calculator [ImPact 2009]. The users start by selecting a specific type of scanner, then they indicate the limits of the scan range and the protocol settings. The software then calculates organ doses and the effective dose, in general the effective dose is obtained for ICRP 60 tissue weighting factors, but recent versions give the option to use ICRP 103 factors. These methods, although they are more precise than the use of conversion coefficients, they only provide an estimate of doses for standard phantoms. Thus, their results should not be applied to examinations of individual patients.

Nevertheless, methods of computational dosimetry continue to advance with the development of more realistic (voxel) mathematical phantoms based on digital images of humans [Zankl 2002], which now allow the estimation of patient-specific doses. An accurate measurement of $CTDI_{vol}$, DLP together with information about the scan region the patient size can let to a good patient dose assessment, within 10%, provided that the appropriate conversion coefficients are used risk [McCollough 2011, DeMarco 2007].

SUMMARY

According to EC requirements, any equipment used for computed tomography shall have a device or a feature informing the practitioner of the quantity of radiation produced by the equipment during the medical radiological procedure. Modern CT scanners usually display $CTDI_{vol}$ and DLP and are able to include this information in a DICOM Radiation Dose Structured Report. As mentioned earlier, this information is useful to evaluate the CT output and to establish local CT Diagnostic Reference Level.

However for the assessment of individual patient doses or CT risk, it is necessary to calculate the organ doses, which requires besides the scanner output, the specific spatial radiation distribution in the patient. This can be determined by using computational methods or appropriate conversion coefficients, which take into account the size or age of the patient. Up to now, size information is often lacking from DICOM information, which makes it more difficult to easily relate the scanner display with actual patient dose. This is especially important for paediatric CT examinations.

In summary, CT dosimetry is well established but there is still some confusion about the appropriate use of the different radiological quantities and some difficulties to estimate individual patient doses. The system could be improved if there was a common database format for dose reporting, including a standard set of protocol names and information about patient height and weight.

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CT diagnostic reference levels

Diagnostic reference dose levels (DRLs) are a part of the quality criteria as laid down in the European Guidelines on Quality Criteria for Diagnostic Radiographic Images [1]. The main objectives of DRLs are to improve a regional, national or local dose distribution by identifying and reducing the number of unjustified high or low values in the distribution, to promote good practice and an optimum range of values for a specified medical imaging protocol. Within this context, Computerized Tomography Dose Index (CTDI) and Dose Length Product (DLP) measurements should be part of the dose optimization program in a CT department. Determination of local DRLs should be done using a sample of 10 standard sized patients, for example the common CT scan of the abdominal region, and mean values of the results should be compared to the abdomen DRL set by professional bodies. In the case of local values being higher than nationally or internationally set DRL, appropriate corrective actions should be applied, so as to reduce the dose to the abdomen.

Numerous international organizations have produced guidelines to facilitate the process of CT radiation dose optimization and the use of CT DRLS in this process. Examples of these organizations are the European Commission (EC), the International Atomic Energy Agency, the International Commission on Radiological Protection, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the American College of Radiology (ACR), the National Radiation Protection Board (NRPB) and the American Association of Physicists in Medicine (AAPM).

Tables 1 and 2 provide DRLs in terms of CTDI and DLP from various national or international studies, respectively [EC 1999, EC 2004, BfS 2010, NRPB 2005, ACR 2009, Brix 2003, Kharuzhyk 2010, JongHak 2010, Nowotny R 2000]. It must be noted that surveys with small sample size, showing only a snapshot of the current situation using scanners of only one or two vendors, can be found more frequently in medical journals. These small surveys will always contain biased data because they are not representative of all scanners and sites. The larger surveys are all carried out on behalf of national authorities such as National Radiological Protection Board (NRPB) in UK, Bundesamt für Strahlenschutz (BfS) in Germany and Bundesministerium für soziale Sicherheit und Gesundheit (BMSG) in Austria with a typical time frame of 5–15 years between updates. Large-scale surveys are necessary to take into account the considerable variations in patient size and differences in scan parameters and settings even within the various sites. It must be noted that most of the DRLs found in the literature are from European countries. The current status of the DRLs in France, Germany, Greece, Italy, the Netherlands, Sweden, Switzerland and the UK is as followed: CT DRLs are set for 4 types of CT exams in France, Italy and Sweden, for 7 in Germany, for 8 in Switzerland and 12 for UK. In Greece, DRL values for 7 types of CT exams are in the process of approval, whereas in the Netherlands, DRLs are not established yet. Finally, recent studies indicate that current DRLs can be further reduced and that DRLs specific to the requirements of clinical indications for particular CT procedures are also desirable [ICRP 2007]. For paediatric patients very limited data are found. Table 3 shows UK DRLs on brain and chest.

*Table 1: Comparison of Diagnostic Reference Levels (DRL) in terms of CTDIvol [mGy] as reported by various countries and organizations. * private communication*

Exam	UK	Germany	Austria	Belarus	Sweden	Sweden*	Swiss	EUR	EUR	ACR	Korea
Author	*NRPB 67*	*BfS, 2010*		*Kharuzhyk*	SSI FS			16262	MSCT		*Jong Hak C*
Year	*2005*	*2010*	*2000*	*2010*	*2002*	*2008*	*2010*	*1999*	*2004*	*2009*	*2010*
Brain	65/55	65	68.9	60	75	65	65	60	60	75	69
Chest	13/14	12	18.9	20	20	12	15	40	10	-	19
Abdomen	14	20	19.8	25	25	13	15	35	25	25	19
Pelvis	14	20	23.5	25	-	-	15	35	-	-	-

Table 2: Comparison of Diagnostic Reference Levels (DRL) in terms of DLP [mGy x cm] as reported by various countries and organizations.

Exam	UK	Germany	Austria	Belarus	Sweden	Sweden*	Swiss	EUR	EUR	ACR	Korea
Author	*NRPB 67*	*BfS, 2010*		*Kharuzhyk*	SSI FS			16262	MSCT		*Jong Hak C*
Year	*2005*	*2010*	*2000*	*2010*	*2002*	*2008*	*2010*	*1999*	*2004*	*2009*	*2010*
Brain	930	950	1275	730	1200	1082	1000	1050	337	-	1056
Chest	580	400	484	500	600	428	450	650	267	-	1234
Abdomen	470	900	1109	600	-	778	650	780	724	-	1844
Pelvis	-	450	589	490	-	-	650	570	-	-	-

*Table 3: Paediatric DRLs for brain, chest and abdomen * the abdomen includes the pelvic area*

	ACR, 2009	NRPB, 2005	BfS, 2010	NRPB, 2005	BfS, 2010
	CTDIvol [mGy]			DPL [mGy x cm]	
Brain 0-1 y	-	35	33	270	400
Brain 5 y	-	50	40	470	500
Brain 10 y	-	65	50	620	650
Chest 0-1 y	-	12	4	200	60
Chest 5 y	-	13	7	230	130
Chest 10 y	-	20	10	370	230
Abdomen 0-1 y	-	-	7	-	170*
Abdomen 5 y	20	-	12	-	330*
Abdomen 10 y	-	-	16	-	500*

The following comments can be made through this literature research:

- The European DRLs should be revised to include MSCT and the new dose quantity CTDIvol.
- DRLs must be established by more European countries. Current values appear to be limited.
- The DRLs that appear in Tables 1 and 2 show large variations. Variations in CTDI are mainly due to variation in the technical protocol used and differences in the CT scanner. Therefore, more standardized protocols could harmonize CTDI DRL values. Variations in DLP are mainly due to variations in the set up. For example in some countries abdomen means the whole abdomen whereas in others it means only the upper abdomen. Also the number of series as well as the definition of series varies. For the abdomen examination the number of series can be from 1 to 4 series between countries.
- DRLs established by other international bodies could be useful for dose optimization processes, especially for other regions of the world with different average sized patients (Asian average weight is lower than the European average weight [Tsapaki 2006]).
- The large variations found, especially for DLP, show that substantial optimization can be achieved. It is possible that different definitions cause this and mutually agreed terms could partly overcome this problem.
- It should be underlined that although European DRLs are set for common radiographic examinations, no European DRLs currently exist for paediatric CT examinations.
- Extensive studies should be carried out to establish paediatric CT DRL.

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Training & Education in CT

Computed Tomography (CT) is one of the most important technological developments of the 20th century. The number of CT procedures is continuously increasing all over the world. This phenomenon is mainly due to the availability of more equipment and the incredible increase of acquisition speed, giving the possibility to perform many more examinations and therefore to study more patients. Due to the shorter scanning times, increasingly patients receive repeated CT examinations especially in the oncology and emergency departments of hospitals and shoulder to pelvic scans are becoming more common. Therefore, justification is continuously questioned.

It is important to assure that radiological health professionals (radiologists, radiographers and medical physicists) are keeping up with this evolution, in order to guarantee "doing more" simultaneously with "doing better". Therefore, the appropriate and continuous training of personnel performing CT procedures and reporting the scans needs to be emphasized.

While there is ample educational material available with respect to protocol optimization for specific clinical tasks, there is a lack of dedicated courses orientated towards the whole core team consisting of the radiologist, a radiographer and a medical physicist.

One of the steps has now been undertaken by the EFRS by formulating a minimum standard in radiation protection education to be included in the initial education curriculum.

Members of WP 1 through reports and a workshop suggest establishing a "core team" to ensure better health service and to identify persons who will be responsible for evaluation and optimization of CT procedures.

A multitude of CT parameters have to be optimized to provide the best compromise between dose and image quality. Protocols therefore need to be standardized by a qualified team of experts that should include a radiologist, a radiographer and ideally also a medical physicist. We suggest that every institution establishes such a "CT core team". This core team should not only be responsible for protocol optimization but also for adequate training of those professionals who prescribes appropriate CT protocols according to indication (radiologists or specially trained radiographers). The core team should also be responsible for training and supervising the CT radiographers that perform the actual scans and ensuring that they are able to adapt the standard protocols to individual patient size and special conditions that require protocol adaptations.

The process of performing CT radiological procedures results in four distinct groups of professionals whose training has to be adapted to their specific needs:

1. The medical practitioners requesting a CT examination. This group requires knowledge about indications for CT, its alternatives and the associated risks and benefits.

2. The core team that defines and optimizes the set of standard scan protocols on a specific scanner (radiographer, medical physicist and radiologist). This team will usually start with a standard set of protocols provided by the manufacturer and adapt it to the local needs. This team requires in-depth knowledge of scan parameters and how to optimize them.

3. The professionals (radiologists, radiographers) who select the CT protocols. This group has to be aware when a particular inaging technique is not appropriate and when to use another technique, according to the patient's clinical indication. They are ultimately responsible for the individual choice of the correct protocol associated with each of the set of available standard protocols at a specific scanner / institution.

4. The radiographers that actually perform the examination. This group requires knowledge about individual routine adaptations required for each patient, such as centring of patients, adapting the scan range, adapting the protocol to patient size, optimizing modality performance in order to obtain the best diagnostic image at the lowest possible dose.

Rapid technological developments require vendor-specific training. Training courses following the acquisition of new equipment are needed, which take into particular account the specific features of the new equipment. The set up of a "core team" is recommended to ensure the best compromise between image quality and dose containment.

Major points for future developments are:

1. *Each CT facility should identify a "core team" responsible for optimisation of CT protocols. This "core team" is also responsible for ensuring training of radiographers and supervision of utilization of scanning protocols.*

2. *Training at least one member of the "core team" should be based on the Core Curriculum for Medical Physicists in Radiology developed by EFOMP.*

3. *There is need for dedicated courses that focus on optimizing CT protocols in general and are geared towards the whole "core team". ESR, EFRS and subspecialty societies can play a major role in establishing these training programs.*

4. *There is a need for a formal accreditation procedure of CT training and education programs established by ESR.*

5. *Education and training recommendations for radiographers have to be established by EFRS and adopt suggestions from other professional bodies and organizations such as ESR and EFOMP.*

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IMPRINT

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