Dosimetry in radiology

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Abstract
The steady growth in the use of ionizing radiation in diagnostic imaging requires a proper management of patients' doses. Dosimetry in Radiology is a difficult topic to address, but it is vital to estimate the dose the patient receives. This article describes the main dosimetric units used and exemplifies doses in radiology in a simple manner through internationally known reference values.

Keywords: *Dosimetry; Radioprotection.*

Introduction

The growing awareness about Radiologic protection is the appropriate response to this problem in our country. Physician staff, radiation physicist and technical staff, are all involved in an improvement process on this issue. Dosimetry in radiology is a difficult topic to address, but it is vital to estimate the dose the patient receives in each radiological study.
The effects of radiation on tissues are classified into 2 categories: stochastic effects (or probabilistic) and non-stochastic effects (non-probabilistic)
Non-stochastic effects (formerly called deterministic effects) have a dose threshold above which they occur; i.e., if the equivalent deposited dose is high enough, a specified types of effects will certainly appear. For example, if an equivalent dose of x-rays exceeds 1 sievert (Sv) (100 REM - Roentgen Equivalent Man - in older units), skin reddening will occur; above a certain dose (over 2 gray [Gy]), eye cataracts will occur, etc.
Stochastic or probabilistic effects are those which have a high probability of occurrence when radiation dose is increased, (but whose severity is independent of the dose level). (it is not dose-dependent). There is no threshold for stochastic effects, since, as the term indicates, they appear in a random manner and are random in nature. The best known examples are cancer and genetic mutations.
The dosimetric units most widely used in radiology for dose quantification include exposure (C/kg_{air} or roentgen [R]), the absorbed dose (Gy or rad), the equivalent dose (Sv or REM) and the effective dose (Sv or REM).
This article describes the main features of these units and exemplifies radiology doses in a simple manner, through internationally known reference values.

Exposure (X)

Exposure is a measure of the ability of an x-ray beam to ionize a mass of air; i.e., it expresses the amount of electrical charge of electrons (Q) generated per unit of mass air (m).
In the International System of Units (SI), the unit is coulomb (C) per kg of air (C/Kg_{air}). However, the conventional unit for exposure is the roentgen (R), equivalent to 2.58×10^{-4} C/kg.
Exposure may be used to measure the radiation received by a chassis, an image intensifier or the patient's skin.
This quantity is widely used because it can be readily measured, but it provides no information about the damage caused to the patient because it does not take into account the radiosensitivity of tissues or organs receiving the radiation.
The so-called "exposure rate" is a measure of the amount of exposure per unit of time. In radiology, it is very common to measure the amount of mR/h detected before or after shielding, and many ionization chambers present these units. For example, it is expected that a standard x-ray tube housing shielding may not allow measuring an exposure rate above 100 mR/h at a distance of 1 meter.

Kinetic energy released per unit mass in ionized air (K)

In imaging diagnosis, exposure (R) and the absorbed dose (rad) are in general numerically similar, but when the SI scheme is used, conversion factors are needed to convert exposure to absorbed dose. For this reason, instead of exposure, the quantity known as kerma (kinetic energy released per unit mass) is used.
Air kerma is defined as kinetic energy (in Joules [J]) transferred from x-ray photons to electrons released per unit mass (kg) of ionized air. The SI unit of kerma is the gray (Gy), equivalent to J/kg.

Absorbed dose (D)

Absorbed dose is the quantity that expresses the amount of energy absorbed per unit mass of a material. It is a generic quantity, defined for any type of radiation or material, used in radiobiology because it is excellent to estimate the damage caused to an organ by a specific type of radiation.
The SI unit for absorbed dose is the Gy, which is equivalent to J/kg. One Gy is equivalent to 100 rads (older units). To convert exposure values (R) to absorbed doses (Gy), material-dependent conversion factors should be used. In the case of x-ray beams used in imaging diagnosis, conversion factors of approximately 0.91 to 0.95 are used for most tissues[1].
Non-stochastic effects that may occur at certain doses are shown in table 1.

Equivalent dose (H)

Radiobiology research studies have demonstrated that for equal absorbed dose values biological damage may differ according to the type of radiation. For example, alpha particles or neutrons produce greater biological damage than X or gamma (γ) radiation for the same absorbed dose.
The quantity known as equivalent dose introduces weighting factors to weight biological effects with regard to the type of radiation. Thus, the equivalent dose is defined as the product of one of these weighting factors and the absorbed dose. For example, alpha radiation has a weighting factor value of 20, while X or gamma rays have a weighting factor of 1 (and therefore the dose equivalent is numerically equal to the absorbed dose).
The SI unit for equivalent dose is the sievert (Sv); it is differentiated from absorbed doses to account for the degree of biological damage. Equivalent dose is a primary indicator of radiological protection, as it specifies radiation limits for occupationally exposed workers. For example, in Argentina the equivalent dose limit for the lens of the eye has been reduced from 150 mSv to 20 mSV; therefore, interventional staff must wear lead glasses to reduce radiation doses as indicated.

Effective dose (E)

The probability of the occurrence of stochastic effects in a specific organ or tissue not only depends on the equivalent dose received by such organ or tissue, but also on the radiosensitivity of the organ receiving the radiation. For this reason, based on the radiation that would be received by a person in his/her whole body, a weighting factor (WT) has been assigned to each organ (International Commission on Radiological Protection, 2007) 2 (table 2).
Each coefficient represents a percentage of radiation in the whole body (100%) and the total sum equals 1. Thus, the effective dose allows differentiation between 2 tests performed with equal radiological parameters, but which will have different values in different parts of the body because different organs are receiving radiation.
Nevertheless, the effective dose is not representative of the dose received by a specific patient, as these coefficients are generic and are obtained from a large number of statistics performed for years in the field of radiobiology.
Table 3 shows representative (statistical) values of effective doses in different studies for comparison purposes and equivalence assessment with regard to the number of chest X-rays. It should be noted that these are only reference values, which are used to raise awareness about the biological damage caused by each specific test. Owing to technological advances, some sites will surely deliver doses below reference levels.

Table 1: Effects on some exposed tissues and organs according to dose.

Organ	Mean absorbed dose (Gy)	Effects
Skin	5	Alopecia
Skin	2 to 5	Erythema
Testicle	> 4	Permanent infertility
Testicle	0.15 to 4	Transient infertility
Ovaries	>3	Permanent infertility
Ovaries	> 0.6	Transient infertility
Lens of the eye	> 2	Cataracts
Bone marrow	0.25	Platelet decrease

Reference levels

One of the main guidelines to be followed in imaging diagnosis is to try to achieve a reliable image of an adequate quality for a proper diagnosis, but applying the lowest radiation dose to the patient. For this reason, it is important to establish optimization activities[2,3].

All imaging studies that use ionizing radiation must be performed with known doses to be able to keep doses As Low as Reasonably Achievable (ALARA) maintaining an adequate image quality.

For each type of study, known doses are established according to the organ receiving radiation, with the aim of administering a minimum doses. For radiological studies, the quantity known as entrance skin air kerma is used, which is measured in mGy or µGy. Table 4 shows the standard reference values, proposed by the European Community, for adult patients in radiological studies[4].

In mammography, a quantity known as mean glandular dose is used. The reference value is 2 mGy (equivalent to about 10 mGy in terms of entrance skin air kerma). It should be noted that the maximum mean glandular dose is with grid 2 mGy.

In computed tomography, the so-called CTDIw and dose length product are used. The main values established by the European Community are listed in Table 5[4].

Both in fluoroscopy and in interventional radiology, the entrance surface air kerma rate (mGy/min) is also used. Guidance values proposed by the International Atomic Energy Agency[5] are listed in table 6.

In addition, the kerma-area product (Gy-cm^2) quantity is used; this is the product of the air kerma at the entrance surface of the skin multiplied by the irradiated area in cm^2. This quantity remains constant as the tube moves closer or away from the patient. The main guidance values proposed by the National Radiological Protection Board are summarized in table 7[6].

The use of reference levels is essential for a proper management of the doses administered to patients[7]. The presence of a medical physicist at radiology services is indispensable for the performance of estimates required for each type of study and for monitoring potential changes in these parameters over time.

Table 2: Coefficient of radiosensitivity according to different organs and tissues.

Tissue / organ	W_t
Breast	0.12
Bone marrow (red)	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Gonads	0.08
Thyroid gland	0.04
Bladder	0.04
Liver	0.04
Esophagus	0.04
Skin	0.01
Brain	0.01
Bone surface	0.01
Salivary glands	0.01
Remainder	0.12

Table 3: Representative effective doses for plain x-rays.

	Effective dose (mSV)	Equivalent number of chest x-rays
Type of procedure		
Limbs x-ray	< 0.01	<0.5
Chest x-ray (PA film)	0.02	1
Skull x-ray	0.07	3.5
Hip x-ray	0.3	15
Dorsal spine x-ray	0.7	35
Lumbar spine x-ray	1.3	65
Pelvis x-ray	0.7	35
Abdomen x-ray	1.0	50
Barium swallow (esophagus)	1.5	75
I.V. urogram	2.5	125
Esophagus, stomach and duodenum	3	150
Small bowel follow-through	3	150
Barium enema	7	350
Nuclear medicine		
CT head	2.3	115
CT chest	8	400
CT abdomen or pelvis	10	500
Nuclear medicine		
Lung ventilation (Xe-133)	0.3	15
Lung perfusion (Tc-99m)	1	50
Kidney (Tc-99m)	1	50
Thyroid gland (Tc-99m)	1	50

mSV: sievert; PA: posteroanterior; CT: computed tomography

Table 4: European Community reference levels for x-ray tests.

Type of test	Reference level (mGy)
Chest (PA)	0.4
Chest (LAT)	1.5
Thoracic spine (AP)	7
Thoracic spine (LAT)	20
Lumbar spine (AP)	10
Lumber spine (LAT)	30
Skull (PA)	5
Skull (LAT)	3
Abdomen (AP)	10
Pelvis or hip (AP)	10
Dental (periapical)	7
Dental (AP)	5

AP: anteroposterior; LAT: lateral; PA: posteroanterior

Table 5: Standard values of parameters used for dose comparison in computed tomography, adopted by the European Community.

Type of study	CTDIw	DLP
Routine head	60	1,050
Chest	30	650
Abdomen	35	780
Pelvis	25	570
Face and sinuses	35	360
Vertebral trauma	70	460
Lung high resolution	35	280
Liver	35	900
Osseous pelvis	25	520

DLP: dose-length product

Table 6: Air kerma guidance values for interventional procedures.Community.

Type of test	Kerma rate (mGy / min)
Normal mode	25
High dose	100

Table 7: Air kerma-area guidance values for interventional procedures.

Fluoroscopy-full test	Kerma-area product (Gy.cm^2)
Lumbar spine	15
Barium enema	60
Intravenous urography	40
Abdomen	8
Pelvis	5

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Conflicts of interest

The authors declare no conflicts of interest.