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CALDose_X: a software for the calculation of absorbed dose to radiosensitive organs and for the assessment of radiological risks for patients submitted to X-ray radiography

CALDose_X: um software para calcular dose absorvida em órgãos radiossensíveis e avaliar riscos radiológicos em pacientes submetidos aos exames de radiodiagnóstico

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Abstract

CALDose_X is a software tool that provides the possibility to calculate incident air kerma (INAK) and entrance surface air kerma (ESAK), two important quantities used in X-ray diagnosis, based on the output of the X-ray equipment. Additionally, the software uses conversion coefficients (CCs) to assess absorbed dose to organs and tissues of the human body, the effective dose as well as the patient's cancer risk for radiographic examinations. The CCs, ratios between organ and tissues absorbed doses and measurable quantities, have been calculated with the FAX06 and the MAX06 phantoms for 65 projections of 21 commonly performed X-ray examinations, for 40 combinations of tube potential and filtration ranging from 50 to 120 kVcp and from 2.0 to 5.0 mm aluminium, respectively, various field positions, for 29 selected organs and tissues and simultaneously for the measurable quantities: INAK, ESAK and kerma area product (KAP). Based on the X-ray irradiation parameters defined by the user, CALDose_X shows images of the phantom together with the position of the X-ray beam. By using true to nature voxel phantoms, CALDose_X improves earlier software tools, which were mostly based on mathematical MIRD5-type phantoms, i.e. poor representations of human anatomy.

Keywords: radiation protection; radiographic phantoms; Monte Carlo method; dosimetry.

Resumo

O CALDose_X é uma ferramenta computacional que fornece a possibilidade de se estimar o kerma incidente no ar (INAK, INcident Air Kerma) e o kerma no ar na superfície de entrada (ESAK, Entrance Surface Air Kerma), duas importantes quantidades utilizadas em radiodiagnóstico, com base na saída do equipamento de raios X. Além disso, o *software* utiliza coeficientes de conversão (CCs) para avaliar a dose absorvida de órgãos e tecidos do corpo humano, a dose efetiva, bem como o risco de câncer em pacientes submetidos a exames radiográficos. Os CCs, razões entre doses absorvidas por órgãos e tecidos e quantidades mensuráveis, foram estimados com os fantomas FAX06 e MAX06 para 65 projeções de 21 exames de raios X comumente realizados, usando 40 combinações entre o potencial do tubo (50 a 120 kVcp) e a filtração (2,0 a 5,0 mm de alumínio), e várias posições do campo. As estimativas foram realizadas para 29 órgãos e tecidos selecionados com saídas simultâneas para as quantidades mensuráveis INAK, ESAK e o produto área-kerma (KAP, Kerma Area Product). Com base nos parâmetros de irradiação de raios X definidos pelo usuário, o CALDose_X mostra imagens do fantoma selecionado juntamente com a posição do feixe de raios X. Ao utilizar a anatomia real do corpo humano contida nos fantomas de voxels, o CALDose_X melhora ferramentas computacionais anteriores, que foram baseadas principalmente em fantomas matemáticos do tipo MIRD5, ou seja, em precárias representações da anatomia humana.

Palavras-chave: proteção radiológica; simuladores; método Monte Carlo; dosimetria.

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Introduction

Conversion coefficients (CCs) between absorbed or equivalent dose to organs at risk and measurable quantities commonly used in X-ray diagnosis have been calculated by Monte Carlo methods for the last 30 years mostly with mathematical MIRD5-type phantoms[1,2]. Consequently, softwares for organ absorbed dose calculations were developed based on MIRD5-type phantoms, like PCXMC[3] or DoseCal[4], however, software using voxel phantoms with improved anatomy was not available.

The purpose of this study was therefore:

a) to calculate organ and tissue CCs for the most common examinations in X-ray diagnosis with the recently developed MAX06 and FAX06 voxel phantoms for various projections and different X-ray spectra;
b) to make these CCs available to the public through a software tool, called CALDose_X (CALculation of Dose for X-ray diagnosis), to be used for the assessment of organ and tissue absorbed doses for X-ray examinations and exposure conditions defined by the user, for determining the effective dose with sex-specific phantoms[5] and for estimating the patient's cancer risks.

Materials and methods

2.1 The MAX06 and the FAX06 phantoms

The MAX06 and the FAX06 phantoms[6] have organ and soft tissue masses in accordance with the reference data from ICRP89[7]. The most important soft tissue organs and the skeletons of the two phantoms are shown in Figure 1.

The EGSnrc Monte Carlo code

The EGSnrc MC code[8] was used to calculate organ and tissue absorbed doses in the FAX06 and the MAX06 phantoms.

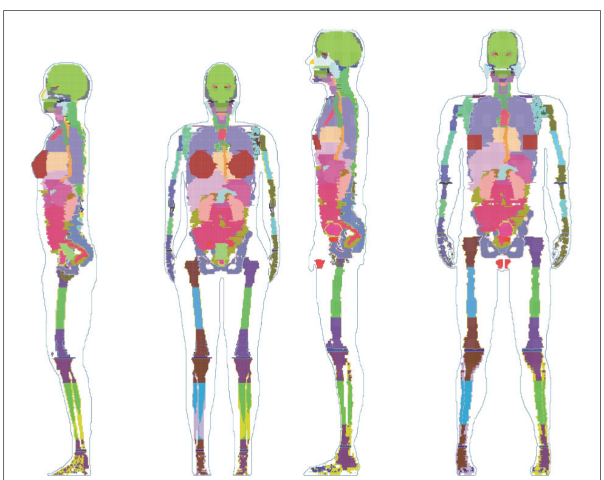

Figure 1. The FAX06 and the MAX06 phantoms (Adipose and muscle tissues removed).

Normalization quantities

According to the concepts outlined in ICRU74[9], CALDose_X presents organ and tissue absorbed doses normalized to the following measurable quantities:

a) incident air kerma (INAK);
b) entrance surface air kerma (ESAK);
c) air kerma-area product (KAP).

Diagnostic X-ray examinations

Calculations have been made for 65 projections of 21 diagnostic X-ray examinations, together with focus-to-surface distances (FSDs) and field sizes in the plane of the image receptor shown in Table 1. The 40 X-ray spectra used were generated from the "Catalogue of Diagnostic X-Ray Spectra and Other Data" IPEM/SR78 by Cranley et al.[10] for constant potential generators, X-ray tubes with 17°

Table 1. Diagnostic X-ray examinations covered by CALDose_X.

Examination	Projection	FSD (MC) cm	Field size cm x cm
Head	AP, PA	80	24 x 30
Head	RLAT, LLAT	85	30 x 24
Cervical spine	AP	80	18 x 24
Cervical spine	RLAT, LLAT	80	18 x 24
Throat	RLAT, LLAT	75	18 x 24
Thorarcic spine	AP	80	20 x 40
Thorarcic spine	RLAT, LLAT	70	20 x 40
Chest	AP, PA	160	35 x 40
Chest	RLAT, LLAT	150	25 x 40
Stomach	AP, PA	40	24 x 30
Stomach	RAO, LPO, LAO	40	24 x 30
Lumbar spine	AP	80	20 x 40
Lumbar spine	RLAT, LLAT	70	20 x 40
Lumbar spine	LPO, RPO	70	24 x 30
Duodenum	AP, PA	45	15 x 15
Duodenum	RAO, LPO	45	20 x 20
Abdomen	AP, PA	80	35 x 40
Pelvis	AP, PA	80	40 x 35
Bladder	AP	75	24 x 20
Colon	LAO, LPO, RAO	75	35 x 35
Heart	AP, PA	45	15 x 15
Heart	LLAT, RLAT	45	15 x 15
Hip Joint	AP, left, right	75	24 x 36
Kidneys	AP, PA	75	36 x 24
LS Joint	LLAT, RLAT	60	18 x 24
Oesophagus	LAO, LPO, RAO	60	15 x 45
Rectum	AP, PA	45	18 x 18
Rectum	LLAT, RLAT	45	18 x 18
Rectum	LPO,RAO	45	18 x 18
Shoulder	AP, left, right	75	24 x 18
Small Intestine	AP, PA	45	24 x 18
Upper Stomach	AP, PA	45	15 x 15

FSD: Focus-to-surface distance; Field size: width x height in detector plane; AP: anterior-posterior projection; PA: posterior-anterior projection; RLAT: right lateral projection; LLAT: left lateral projection; RAO: right anterior oblique; LAO: left anterior oblique; RPO: right posterior oblique; LPO: left posterior oblique target angles, peak potentials between 50 and 120 kV and total beam filtrations of 2.0 to 5.0 mm Al.

Results

Figure 2 shows the main user interface of the CALDose_X software. Here, the user can define the institution and the exposure parameters of the X-ray unit, can calculate the INAK and ESAK, can select the X-ray examination, the projection and field position and can pass patient data to CALDose_X. When all data have been filled into the CALDose_X form and the sex of the patient was defined, the image shown in Figure 3 pops up, which is a visualization of the exposure geometry of the examination chosen by the user.

Clicking on "Calculate Dose" and after selection of the normalization quantity, Table 2 appears with the results for the examination and the exposure conditions chosen by the user.

Discussion and conclusions

CALDose_X can be used:

- To calculate the INAK based on the output curve of the X-ray equipment;

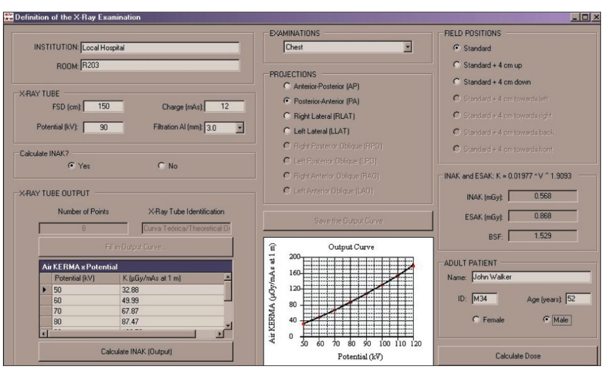

Figure 2. CALDose_X user interface for the calculation of the INAK (ESAK), the selection of the X-ray examination and the definition of the patient data.

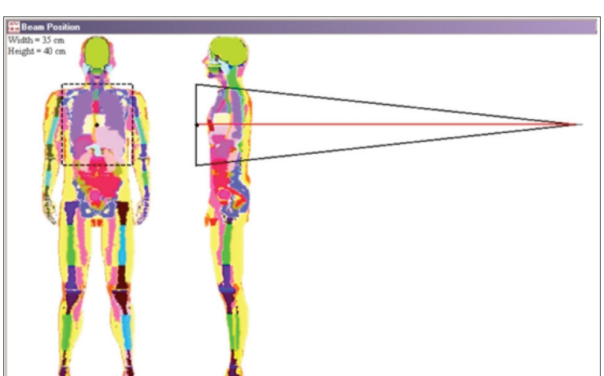

Figure 3. Visualization of the X-ray exposure geometry chosen by the user.

- to assess the ESAK in order to control compliance with diagnostic reference levels,
- to calculate organ and tissue absorbed doses for patients with anatomies similar to the MAX06 and the FAX06 phantoms;
- to assess the effective dose based on ICRP103 and/or the patient's cancer risk;

Table 2. CALDose_X results for a PA chest radiograph for a 52-year old male patient

Institution:	Local Hospital	
Room:	R203	
X-ray tube identification:	Theoretical Output 3,0 mm Al	
Patient:	Male	
Age:	52 years	
Name:	John Walker	
Patient identification:	M34	
Calculation date:	May 17th 2009 CALDose_X 3.4	
Exposure conditions		
Max06:	Chest, posterior-anterior (PA)	
Image in front of the body	90 kVcp 3.0 mm Al 17 Deg Tungsten IPEM/SR78	
Mean spectral energy:	46.8 keV	
Absorbed fraction:	0.65	
Source-to-detector (film):	188 cm	
Source-to-skin:	160 cm	
Field size in detector plane:	35 cm x 40 cm	
Field position:	STANDARD	
Charge:	12 mAs	
Organ/tissue	mGy	%
Esak	0.87	1.42
Adrenals	0.19	2.18
Brain	0.00	2.60
Colon wall	0.03	1.11
Breasts	0.08	2.63
Kidneys	0.14	0.57
Liver	0.12	0.26
Lungs	0.22	0.22
Oesophagus	0.13	1.56
Pancreas	0.09	1.03
Small intestine wall	0.02	0.95
Skin entrance 7.2 cm X 7.2 cm	0.89	1.42
Spleen	0.15	0.78
Stomach wall	0.10	0.96
Thymus	0.08	2.56
Thyroid	0.03	4.77
Lymphatic nodes	0.09	0.63
BSC dose mainly in beam volume	0.82	0.14
RBM dose mainly in beam volume	0.19	0.16
Weighted male whole body dose	0.09	0.44

Risk of cancer incidence 0.63 cases per 100,000

Risk of cancer mortality 0.50 cases per 100,000

- to demonstrate how organ and tissue absorbed doses, i.e. the radiation risk for the patient, depend on the proper selection of the exposure parameters. This information can be used in educational programs to train radiologists and technicians to understand how to perform X-ray examinations with the minimum exposure to the patient;
- to compare organ and tissue absorbed doses, effective doses or radiation risks from different radiological procedures, or from different X-ray units, or from different hospital, etc., to identify high and low risk examinations, or cases of good and bad practice; and
- to make risk assessments for surveys on radiological exposures, taking into account risk factors for the age and gender distribution of the patient population under consideration.

CALDose_X can be downloaded gratis from www.grupodoin.com. Together with the downloaded software comes a copy of the official CALDose_X release paper[11].

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