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A new method for effective dose calculation based on the ambient dose height distribution

Abstract: The realistic determination of effective dose of the staff in diagnostic radiology has been a challenge both for personal dosimetry and ambient dose measurement. A model for dosimetry of occupational exposure is presented that allows direct determination of effective dose from measured or even manufacturer given ambient dose distribution in front of the personnel. This model considers a wide range of radiation energies, different radiation protection situations, and gender effects.

Keywords: Diagnostic radiology, ambient dose equivalent, effective dose, radiation exposure, occupational exposure, radiation protection.

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1 Introduction

Effective dose is a widely used quantity to assess the ionizing radiation related. In radiation protection practice, it is usually estimated based on measurements of the personal dose equivalent which "is taken as an assessment of the effective dose under the assumption of a uniform whole body exposure" (ICRP 103) [1].

Radiology is the area of occupational exposure in which most of the radiation exposed personnel is employed and where this assumption generally is not fulfilled, because only a part of the body is protected by the protective clothing.

To solve the difficulties with the highly heterogeneous exposure of the medical personnel during radiologic interventions different techniques to assess the effective dose using one or two dosemeters were suggested for monitoring measurements [2].

With this work an offline method is presented, allowing effective dose calculation through measurement of a height distribution of ambient dose. Therefore, this method can be used for analyzation and optimization of working places in a faster and more accurate way than through analyzation of monthly readout dosemeters.

2 Materials and methods

Using voxelized anthropomorphic phantoms a height distribution of gender specific conversion factors and correction factors from ambient dose to effective dose is developed, enabling a direct conversion of a measured or even manufacturer given ambient dose distribution to effective dose.

This model already includes different radiation protection clothing and the effects of beam hardening of the radiation field through different thicknesses of protection clothing. Additional radiation protection equipment is included in the ambient dose distribution - measured at the personnel position [3].

The magnitude of the effective dose E is defined according ICRP 103 [1] as:

$$\mathbf{E} = \sum_T \boldsymbol{w_T H_T} \quad \text{with} \quad \sum_T \boldsymbol{w_T = 1} \qquad (1)$$

where H_T is the equivalent dose in an organ or tissue and w_T is the tissue weighting factor for the tissue T. The tissue weighting factors are sex- and age-averaged for all organs and tissues with H_T:

$$\boldsymbol{H_T = (H_{T,male} + H_{T,female})/2} \qquad (2)$$

With the energy-dependent conversion factor $f_{k,t}$

$$\boldsymbol{f_{k,T} = H_T/H^*(10)} \qquad (3)$$

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one obtains a relation between E and the *H*(10)*. The organ-related conversion factors of $f_{k,t}$ are taken from SSK 43 [4].

Table 1: Example for the height dependent correction factors f for $w_{T,male}$. Target regions with 125.0 ≤ z < 135.0 mm (male; lead apron 0.35 mm Pb; mean tube voltage 85 kV). Organ ID from ICRP 110 [5].

Organ ID	Target region	z-coordinate (male) in mm	f = fraction of $w_{T,male}$ in %	f x $w_{T,male}$ in %
87	Hart wall	134.6	100	0.92
50	Thoracic spine, spongiosa	134.4	16.1	1.932
62-65	Breast-a + Breast-g	132.45	100	12
44	Ribs, spongiosa	131.9	16.1	1.932
127	Spleen	126.8	100	0.92
95	Liver	125.7	100	4
72	Stomach wall	125.0	100	12

Our model is based on the fact that in an anthropomorphic phantom the organs have a definite height for male and female respectively and that there is a correlation between the measured ambient dose equivalent in a definite height and the dose of the organs in the corresponding part of the body. For most of the organs and tissues relevant for the effective dose the height of the mass center (z-coordinate) needed for our calculation could be taken directly from ICRP 110 [5]. For more extended organs (red bone marrow, skin, muscle, lymphatic nodes, bone surface) the distribution of the organ mass in the body was taken into account separately based on data from ICRP 89 [6] (correction factor *f* in **Table 1** in accordance to the relative organ mass with regard to the height of the target region). An example for the height dependent correction factors are shown in **Table 1**.

The average energy of the radiation was calculated for different radiation protection clothing and different permanent protective equipment [3]. The energy hardening caused by the lead equipment was taken into account [7; 8].

In accordance with the step distance chosen by the measurements, the resulting dose values accompanying the z-coordinate are summarized referring to an average height (see **Table 2**).

3 Results

For a first application of this new method, effective dose for the examiner at interventional computed tomography examinations was calculated for a clinical scanner (Toshiba Aquilion 64) with different gantry angulations and a male and female examiner phantom wearing radiation protection vests of different Pb equivalent thicknesses and a thyroid protector. The positioning for the measurement was adjusted according to the local radiologist. No additional radiation protection equipment like ceiling mounted shields were used, since these are used very unfrequently. The values of *H*(10)* were measured in steps of 10 mm. The used coefficients calculated with the model to determine *E* are given in tabular form in **Table 2**, the results are shown in **Table 3.**

From the measured values of *H*(10)* in height of the breast values for the personal dose $H_p(10)$ were derived and compared with the calculated values of E (see **Table 4**).

4 Discussion

The model described provides an easy method to assess the effective dose of the staff based on the height distribution of the ambient dose. This distribution is easy to measure; sometimes it could be taken from data of the manufacturer. The first results (see **Table 3; 4)** show an underestimation of the effective dose by the personal dose by a factor of 1.5 – 2.1. This is in accordance with results in the literature [2; 9].

The model is very useful not only to estimate E in a predetermined radiation protection situation and to correct inaccuracies of the personal dosimetry but also to optimize the staff radiation protection by minimizing the effective dose [10].

In this context the effective dose is the most important dose quantity and most dose limits refer to this quantity. In radiation protective practice, it is usually estimated based on individual measurements of the personal dose. If $H_p(10)$ is measured with a single dosimeter underneath the protective apron (the standard in Germany) the effective dose is underestimated in many situations. In fact a monthly dose value “zero” is often indicated. Therefore an optimization of radiation protection is very limited based on standard dosimetry values.

Table 2: Coefficients for calculation of the effective dose from measured values of H* in 10 mm steps (mean tube voltage 120 kV)

	♂	♀	♂	♀
Height [mm]	**0.35 mm Pb**	**0.35 mm Pb**	**0.50 mm Pb**	**0.50 mm Pb**
170	0.0104	0	0.0104	0
160	0.0345	0.0110	0.0345	0.0110
150	0.0455	0.0339	0.0454	0.0339
140	0.0155	0.0468	0.0088	0.0461
130	0.0379	0.0320	0.0216	0.0182
120	0.0043	0.0225	0.0025	0.0129
110	0.0164	0.0047	0.0100	0.0034
100	0.0030	0.0154	0.0022	0.0093
90	0.0066	0.0171	0.0038	0.0097
80	0.0096	0	0.0055	0
70	0.0003	0.0004	0.0002	0.0002
60	0.0001	0.0001	0.00005	0.00004
50	0	0.0001	0	0.0
40	0.0001	0	0.0001	0.0001
30	0.0008	0.0042	0.0008	0.0042
20	0.0032	0	0.0032	0

Table 3: Calculated effective dose E from measured values of H* in 10 mm steps based of the coefficients of Table 2 (mean tube voltage 120 kV).

	Effective dose E ♂	**Effective dose E ♀**
0.35 mm Pb	0.53 µSv/100 mAs	0.52 µSv/100 mAs
0.5 mm Pb	0.42 µSv/100mAs	0.42 µSv/100mAs

Table 4: Quotient of the effective Dose E calculated with the model described and the expected value of the personal dose $H_p(10)$.

	$E/H_p(10)$ ♂	**$E/H_p(10)$ ♀**
0.35 mm Pb	1.53	1.49
0.5 mm Pb	2.21	2.10

Author's Statement

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