MEDICAL IRRADIATION AND THE USE OF THE "EFFECTIVE DOSE EQUIVALENT" CONCEPT

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The Effective Dose Equivalent Concept defined by the ICRP (5,6) considers the total risk from occupational irradiation including both hereditary and somatic effects. In the field of medical irradiation there is a tradition to report the genetically significant dose equivalent as an index of harm to the population to this type of irradiation although it only includes the genetical effects.

This paper will deal with the definition of a similar concept for somatic effects which added to the GSD will better approach an index of total harm to the population from medical irradiation.

By applying the linear-dose effect relation one can transform the weighting factors for total risks recommended by ICRP to weighting factors for somatic effects. Another weighting factor M_S has to be used which takes into account the dependence of the latence period for occurence of malignant disease and the variation of the incidence with time. On this basis a somatically significant dose equivalent can be defined as "the dose equivalent which if received by every member of the population, would be expected to produce the same total somatic injury to the population as does the actual dose equivalent received by the various individuals". In the first approximation it can be written as

$$SSD = \sum_{g,j,k} \left(\frac{N(g,j,k)}{N_{tot}}\right) \sum_{i} M_S(g,i,j,k)\cdot\omega_S(g,i,j,k)\cdot\bar{H}(g,i,j,k)$$

where g = (FM) or (M) denote the sex

$\frac{N(g,j,k)}{N_{tot}}$ = the relative frequency of the age class 'k' subjected to class 'j' exposure (N_{tot} = the total number of individuals in the population)

$\omega_S(g,i,j,k)$ = the relative weighting factor for somatic effects in tissue or organ 'i' of individuals in age class 'k' subjected to class 'j' exposure.

$\bar{H}(g,i,j,k)$ = average dose equivalent to tissue or organ 'i' in individuals of age class 'k' subjected to class 'j' irradiation.

$M_S(g,i,j,k)$ = malignancy significant factor for a malignant disease of organ or tissue 'i' in individuals of age class 'k' subjected to class 'j' radiation.

In the second approximation the malignancy significant factors are taken to one i.e. $M_S \approx 1$ which is an overestimation, because M_S by definition is < 1. But still it is required a lot of detailed information about age distributions which are very seldom available in practice. Therefore one must assume that there is no age dependence in the incidence and in the frequency distributions. Then one arrives to the following expression which is very similar to the 'somatic dose index' suggested by Laws and Rosenstein (8).

$$SSD = \sum_{g,i,j} \left(\frac{N(g,j)}{N_{tot}}\right) \cdot \omega_S(g,i,j) \cdot H(g,i,j)$$

The approximation of no sex-dependence makes the final expression for the somatically significant dose equivalent

$$SSD = \sum_{i,j} \left(\frac{N(j)}{N_{tot}}\right) \sum_{i} \omega_S(i,j) \cdot \bar{H}(i,j) = \sum_{i} \left(\frac{N(j)}{N_{tot}}\right) \cdot H_{S,E}(j)$$

where $H_{S,E}(j) = \sum_{i} \omega_S(i,j) \cdot \bar{H}(i,j)$ is the somatically effective dose equivalent for the type of irradiation 'j'.

The incidence for fatal somatic effects and the relative weighting factors for somatic effects in different organs or tissues 'i' are given in table 1 (5,6,12). Morbid somatic effects will not be considered in the present paper.

TABLE 1. Incidence for fatal somatic effects and the relative weighting factors for somatically effective dose equivalent (5,6,12).

Organ or tissue	Incidence percent per Sv	Relative somatic effective weighting factors ω_S
Breast	0.25	0.19
Red marrow	0.20	0.16
Lung	0.20	0.16
Thyroid	0.05	0.04
Bone surfaces	0.05	0.04
Remainder	0.50	0.40
Skin	0.01	0.01
Total	1.26	1.00

DIAGNOSTIC X-RAY EXAMINATIONS

Estimation of organ doses from diagnostic X-ray procedures can be made either by direct measurements of absorbed dose or by calculations. The Monte Carlo method has been used extensively for calculation of absorbed dose received by each organ of interest during diagnostic X-ray examinations.

TABLE 2. Calculation scheme for the somatically effective dose equivalent $H_{S,E}(j) = \sum_i \omega(i) \cdot D(i,j)$

	Average absorbed dose to various organs and tissues from different X-ray examinations D(i,j) mGy							
	Breast	Red Marrow	Lung	Thyroid	Bone surfaces	Remainder	Skin	$H_{S,E}$ mSv
NERVOUS SYSTEM								
Head (skull)	0.04	0.54	0.04	3.7	1.00	10.0	11.76	1.87
Head-angiography	-	5.87	-	-	-	-	-	-
THORAX PLUS NECKORGANS								
Heart and Lung	1.95	0.73	2.9	0.97	2.6	11.1	10.5	6.62
Angiocardiography	-	1.42	-	-	-	-	-	-
Whole chest	0.27	0.13	0.42	0.10	0.26	0.66	0.78	0.48
Chest-mass survey	-	0.72	-	-	-	-	-	-
Tomography (Lung)	-	1.93	-	-	3.18	20.1	17.0	-
DIGESTIVE ORGANS								
Barium swallow (stomach)	3.4	4.5	8.6	1.01	6.7	30.2	26.8	17.8
Barium meal (intestine)	0.81	5.2	1.0	0.06	5.3	38.6	35.6	20.4
Barium enema (colon)	0,17	5.9	0.25	0.05	9.2	18.9	17.8	10.8
Stomach-mass survey	-	0.60	-	-	-	-	-	-
Gallbladder	0.37	1.39	1.29	0.02	1.48	15.5	10.36	7.8
UROGENITAL ORGANS								
Abdomen-Kidney Urether and Bladder	0.29	1.26	0.14	0.02	2.9	9.3	7.5	4.9
Urography	3.7	3.4	0.67	0.21	4.7	38.6	16.0	18.5

TABLE 2. Continued

	Breast	Red marrow	Lung	Thyroid	Bone surfaces	Remainder	Skin	$H_{S,E}$ mSv
Cystography (Bladder)	-	3.0	-	-				
Abdomen-angiography	-	3.8	-	-	-	-	-	-
Abdomen-obstretic	-	2.3	-	-	-	-	-	-
Salpinography	-	1.81	-	-	-	-	-	-
Placentography	-	-	-	-	-	-	-	-
Other	-	0.99	0.60	0.01	-	-	-	-
SKELETON, EXTREMITIES								
Dental (Full mouth 14 films)	0.1	0.05	0.01	0.5	0.025	*)	0.3	1.17
Cervical spine	0.05	0.33	0.12	4.1	1.00	3.4	8.8	2.5
Thoracic spine (dorsal)	4.0	1.95	5.6	5.0	3.4	9.7	9.1	6.3
Lumbar spine	1.58	2.3	0.95	0.08	4.1	11.5	16.8	7.3
Lumbo Sacral joint	0.03	2.9	0.23	0.01	2.7	7.1	6.0	4.1
Hip and upper femur	0.03	0.80	0.04	0.01	2.7	7.1	6.0	3.7
Leg and foot	0.01	0.11	0.01	0.20	0.18	0.18	1.25	0.24
Clavicle and Shoulder	0.64	0.35	0.99	0.50	-	-	-	-
Arm and Hand	-	-	-	0.01	-	-	-	-
OTHER								
Mammography	-	-	1.43	-	-	-	-	-
Lymphoangiography	-	-	2.03	-	-	-	-	-

*)Salivary glands 6 mGyx0.01
Brain 0.2 mGyx0.01
Remaincer 0.005 mGyx0.38

Estimation of the somatic effective dose equivalent needs data on the absorbed dose to breast, red bone marrow, lung, thyroid, bone surfaces, skin and up five more highly exposed organs or tissues. The absorbed dose to these organs from various types of X-ray examinations are given in table 2. These data are extracted from measured and calculated data published by various authors (1,8,3).

The somatically effective dose equivalent $H_{S,E}$ for the various types of X-ray examinations which has been derived from the absorbed dose values in table 2 by applying the weighting factors given in table 1 are given in the right column of table 2. The highest somatically effective dose equivalent are received by X-ray examinations of the small intestine (barium meal), descending urography (IVP) and the stomach and oesophagus (barium swallow) which all give values in the order of 18-20 mSv (1.8-2 rem).

DIAGNOSTIC USE OF RADIOPHARMACEUTICALS

The absorbed dose to various organs and tissues can be derived from the well known MIRD formalism but this must be extended to involve also the target dose resulting from the radioactive material distributed within the remaining parts of the body. Generally, the absorbed dose D(i) in any target organ (i) is composed of three part'

$$D(i) = D(i \leftarrow i) + \sum_h D(i \leftarrow h) + D(i \leftarrow RB)$$

where $D(i \leftarrow i)$ is the absorbed dose due to self-irradiation from the target organ (i), $\sum D(i \leftarrow h)$ is the absorbed dose due to irradiation from specified source organs (h), $D(i \leftarrow RB)$ is the absorbed dose due to irradiation from radioactivity in the rest of the body (RB).

In medical applications a unit bolus injection of activity A_o is often used which means that the cumulated activity in an organ can be written as

$$\tilde{A}(o,\infty) = \tau_k \cdot A_o$$

where τ_k is the mean residence time of the radioactivity in region k. The somatically effective dose equivalent may thus be given as

$$H_{S,E} = A_o \cdot \sum_i \omega_S(i) \; \{\tau(i) \cdot S(i \leftarrow i) + \sum_h \tau(h) \cdot S(i \leftarrow h) + \tau_{RB} \cdot S(i \leftarrow RB)\}$$

where the mean absorbed dose per unit cumulated activity S for the remainder of the body (i.e. total body excluding the source volumes) may be represented by the following expression(11).

$$S(i \leftarrow RB) = S(i \leftarrow WB) \frac{m_{WB}}{m_{RB}} - \sum_h S(i \leftarrow h) \frac{m_h}{m_{RB}}$$

where $S(i \leftarrow RB)$, $S(i \leftarrow WB)$ and $S(i \leftarrow h)$ are the mean absorbed dose per unit cumulated activity for the target region, considering the remainder of the body, the total body and the h:th source volume respectively.

Taking into account the relationship between the residence time for the rest of the body, total body and the target organs ($\tau_{RB} = \tau_{WB} - \sum_h \tau_h$) the somatic effective dose equivalent may be giver

TABLE 3. Somatic effective dose equivalent (μSv/MBq) and absorbed dose to 'critical' organs per unit of administered activity for some radiopharmaceuticals (1 μSv/MBq =3.7 mrem/mCi;1 mrem/mCi = 0.27 μSv/MBq)

Compound	Function or organ examined (Average administered activity MBq) (1 mCi = 37 MBq)	Absorbed dose μGy/MBq 'Critical' organs	Average whole body	$H_{S,E}$ μSv/MBq
Cr-51 EDTA	GFR (3.2)	kidney:80-120 -	3	9-16
Tc-99m colloids	liver (300)	liver: 92, spleen:57	5.1	12
Tc-99m DTPA	kidney (150)	kidney:24	1.7	3.5
Tc-99m MAA, HAM	lung (70)	lung:57, liver:10	3.7	15
Tc-99m pertechnetate	brain; thyroid (400, 60)	thyroid:35	38	8
Tc-99m-phosphates	skeleton (350)	skeleton:15	4,7	5
I-123 iodine	hypothyroid (20)	thyroid:2 400	11	100
	euthyroid "	thyroid:5 400	9	220
	hyperthyroid "	thyroid:13 000	8	520
I-125-iodide	hypothyroid (1.4)	thyroid:250 000	140	10 000
	euthyroid "	thyroid:470 000	260	19 000
	hyperthyroid "	thyroid:800 000	320	32 000
I-131-iodide	hypothyroid (0.4)	thyroid:230 000	80	18 000
	euthyroid "	thyroid:570 000	110	41 000
	hyperthyroid "	thyroid:1 000 000	180	80 000
Au-198 colloid	liver (40)	liver:11 000	380	1 230

by the following expression

$$H_{S,E} = A_o \sum_i \omega(i) \{\tau(i)\cdot S(i\leftarrow i)+\sum_h \tau(h)\cdot S(i\leftarrow h)+(\tau_{WB}-\sum_h \tau(h))\cdot (S(i\leftarrow WB) \frac{m_{WB}}{m_{RB}} - \sum_h S(i\leftarrow h) \frac{m_h}{m_{RB}})\}$$

The somatically effective dose equivalent per unit of administered activities for some of the most frequent examinations are given in table 3 together with the absorbed dose to some critical organs.

The calculation of these values are mainly based on the data summarized by Kaul and Roedler (7,10,9)

RADIATION THERAPY

There are surprisingly enough no complete information on various organ doses available in the literature for an estimation of somatically effective dose equivalent in radiation therapy procedures. The high absorbed dose used in radiation therapy makes it further difficult to estimate which weighting factors should be used in the calculations. Therefore it seems not at the present time to be meaningful to make any estimation of somatically effective dose equivalent in radiation therapy.

Attempts have, however, been made to calculate leukemia significant dose equivalent based on absorbed dose to the marrow and a leukemia significant factor (2).

In table 4 is given the leukemia significant dose equivalent LSD for beam therapy (μSv per person and year) in Japan.(2,4).

SOMATICALLY SIGNIFICANT DOSE EQUIVALENT

By applying the relative frequency of various types of X-ray examinations and examinations with radiopharmaceuticals to the somatically effective dose equivalent one can easily arrive to an approximative value of the somatically significant dose equivalent.

TABLE 4. The leukemia significant dose equivalent LSD (μSv per person and year) from beam radiation therapy in Japan 1971 and 1978 (2,4)

Irradiation Source	LSD (μSv per person and year)			
	Male		Female	
	1971	1978	1971	1978
X-ray: HVL 2 mm Al	5.9	-	18	1.5
X-ray: HVL 0.5-2 mm Cu	2.6	-	12	0.1
Co-60 gamma rays	39	31	180	9.5
Accelerator: photons 4-30 MV	13.6	37	85	63
Accelerator: electrons 8-35 MeV	4.8	0.4	7.4	2
Total	66	68	302	230

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