ASSESSMENT OF AGE-SPECIFIC RADIATION RISKS TO PATIENTS WITH NON-UNIFORM DOSE DISTRIBUTION

T.Komppa and A.Servomaa

Finnish Centre for Radiation and Nuclear Safety,
P.O. Box 14, FIN-00881 Helsinki, Finland

ABSTRACT - In medical radiology, a typical radiation dose distribution within the patient's body is extremely non-uniform, and the patients' typical age distribution is clearly different from that of the whole population. The effective dose and the nominal probability coefficients, as defined in the 1990 Recommendations of the ICRP for radiological protection and for assessment of risks in general terms, apply to workers and to the whole population. For estimating the risks from a known exposure to a known population, e.g. to patients in certain X-ray examinations, it is better to use specific data relating to that exposed population.

The modified relative risk model of the BEIR V (1990) report allows assessment of the radiation risk as a function of the age at exposure and the time after exposure, separately for males and females. Fitted parameters are given for five specific organs or organ groups. The model is directly applicable if the dose distribution is uniform within each of the organ groups. Otherwise, some extra information or extra assumptions are needed for risk assessment. In this work, the BEIR V model is used with Finnish statistical data on cancer and mortality. Some approximative assumptions are presented and discussed, applied to selected X-ray examinations, and compared with uniform exposure of the population.

INTRODUCTION

In the 1990 Recommendations of the ICRP (1), average coefficients for the probability of radiation-induced fatal cancer are defined for twelve organs or tissues and for the remainder group. The tissue weighting factors and the effective dose are then defined, considering the estimated loss of life expectancy and the contributions of non-fatal cancers and genetic effects. The quantities used in the definitions are averages calculated for several populations, both sexes and a wide range of ages. Because of this averaging, there is no explicit dependence on age, time or sex in the definition of the effective dose.

The BEIR V report (2) presents a modified relative risk projection model with explicit dependence on the age at exposure, time after exposure and sex. The model can be applied together with national mortality and cancer mortality rates and age distributions, and with the age distributions of specific groups. It is one of the risk projection models used by the ICRP in preparing the 1990 Recommendations. With some modifications, it is also used by the NRPB (3). The use of the radiation risk projection models - and the associated uncertainties and problems - have been discussed by many authors (1-7). If the dose distribution within the body is strongly non-uniform, a special problem arises from the application of collective groups of organs (8,9).

METHODS

In principle, the radiation-induced age-specific excess mortality rate, R(a;e,D) is the sum of all organ-specific mortality rates, $r_k(a;e,d_k)$ caused by the organ doses, d_k:

$$R(a;e,D) = \sum r_k(a;e,d_k)$$

where a is the age, e is the age at exposure and D is a symbol for the configuration of all organ doses. In practice, certain organ-specific functions, r_k, may be available for some organs, and one or more organ groups may have given group-specific functions, r_g :

$$R(a,e,D) = \sum r_k(a,e,d_k) + \sum r_g(a,e,d_g)$$

The problem is how the group-specific doses, d_g, should be estimated if the dose distribution is not uniform within each of the organ groups. The problem can be examined within any one of the groups; in the following, the group subscripts are deleted: $r \equiv r_g$, $d \equiv d_g$, and $\sum r_k$ is the sum of organ-specific mortality rates within the group under consideration:

$$r(a,e,d) = \sum r_k(a,e,d_k)$$

In the following, some simplifying assumptions are made, and the resulting relations are presented for the absolute (A) and relative (R) risk models.

In functions r and r_k, the dose dependence is assumed to be separable;

A: $r(a,e,d) = f(d)\ g(a,e) = \sum f_k(d_k)\ g_k(a,e)$

R: $r(a,e,d) = f(d)\ g(a,e)\ r_0(a) = \sum f_k(d_k)\ g_k(a,e)\ r_{0k}(a)$

Functions r_0 and r_{0k} are the baseline mortality rates of the population, and $r_0 = \sum r_{0k}$.

The age and time dependence is assumed to be the same for all organs in the group: $g_k \equiv g$;

A: $f(d) = \sum f_k(d_k)$

R: $f(d)\ r_0(a) = \sum f_k(d_k)\ r_{0k}(a)$

A simple linear dose response function, $f = \alpha d$ and $f_k = \alpha_k d_k$, is assumed for all organs in the group;

A: $\alpha\ d = \sum \alpha_k d_k$

R: $\alpha\ d\ r_0 = \sum \alpha_k d_k r_{0k}$

If the dose distribution is uniform, $d_k \equiv d$ for all organs;

A: $\alpha = \sum \alpha_k$

R: $\alpha\ r_0 = \sum \alpha_k r_{0k}$

These relations apply to any dose configuration because the risk coefficients, α and all α_k, are independent of the organ doses. For practical calculations, more information or extra assumptions about the unknown α_k coefficients are needed. The four equations above are then solved simultaneously with the extra relations.

First assumption: All coefficients within the group are the same, $\alpha_k \equiv \alpha'$;

1A: $\alpha = n\ \alpha'$ and $d = \sum d_k / n$ (n is the number of organs in the group)

1R: $\alpha = \alpha'$ and $d = \sum d_k r_{0k} / r_0$

If, in the R model, the absolute risk coefficients are required to be equal ($\alpha_k r_{ok} = C$) then

1R': $\alpha\ r_0 = n\ C$ and $d = \sum d_k / n$

Second assumption: The ratios of the coefficients are furnished with specific weighting factors, w_k ;

$\alpha_k = w_k \alpha'$ and $\sum w_k = 1$

2A: $\alpha = \alpha'$ and $d = \sum w_k d_k$

2R: $\alpha\ r_0 = \alpha' \sum w_k r_{0k}$ and $d = \sum w_k r_{0k} d_k / \sum w_k r_{0k}$

If, in the R model, the absolute risk coefficients need to have constant ratios ($\alpha_k r_{ok} = w_k C$), then

2R': $\alpha\ r_0 = C$ and $d = \sum w_k d_k$

In the following examples, the BEIR V relative risk model is applied to Finnish demographic data, mortality and cancer mortality rates, patients' age distribution, and estimated organ doses in a typical chest CT examination. The lifetime risk projections are calculated using two of the assumptions above: 1R and 2R'. The weights, w_k for the 2R' case, are calculated from the nominal probability coefficients of ICRP 60 (1). For comparison, the same lifetime risk quantities are also calculated from a hypothetical uniform dose distribution corresponding to the effective dose of the same chest CT examination.

RESULTS

The most prominent organ doses (in mSv) in the chest CT examination are: lungs 18; breasts 16; red bone marrow 2; digestive organs: oesophagus 15, stomach 2, liver 3, gall bladder 1, pancreas 3, spleen 3; and other organs: adrenals 3, kidneys 1, skin 5, thymus 25, thyroid 7, muscles 5, bones 9 mSv. According to the ICRP 1990 Recommendations (1), the remainder organ dose is 13 mSv, and the effective dose 6 mSv. These values are rounded averages of a sample collected from Finnish hospitals. The weighted group-specific doses according to the 2R' case are 3.2 mSv for the digestive organs and 7.5 mSv for the BEIR V group of other organs.

The lifetime risk projections: the excess lifetime risk (ELR), the risk of exposure-induced death (REID), and the loss of life expectancy (LLE) are calculated according to Thomas et al. (4). The REID values, calculated as a function of age at exposure, are shown in Figure 1. The mean values of REID and LLE, according to the relevant age distributions, are presented in Table 1.

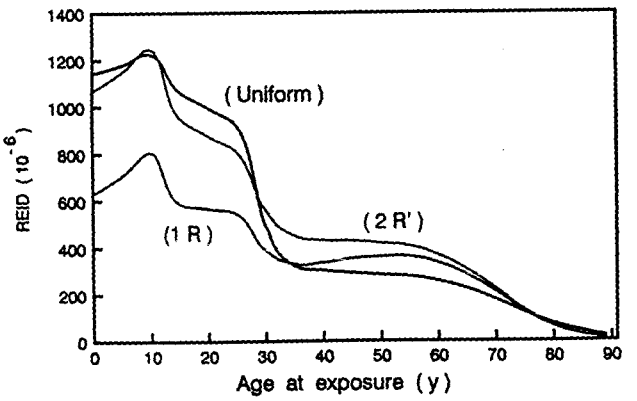

Figure 1. The REID for Finnish females in chest CT examinations, calculated using two different assumptions (1R and 2R' as defined in the text) and a uniform dose distribution for comparison.

Table 1. Mean REID (10^{-6}) and LLE (10^{-6}y) for Finnish females in chest CT examinations and with uniform dose distribution.

Target group:	CT Patients		CT patients		CT patients		Population	
Assumption:	1R		2R'		Uniform		Uniform	
Quantity:	REID	LLE	REID	LLE	REID	LLE	REID	LLE
Leukaemia	16	200	16	200	47	590	37	740
Breast cancer	44	910	44	910	16	340	32	790
Respiratory	180	2090	180	2090	60	700	50	660
Digestive	50	480	70	660	130	1240	270	2720
Other cancers	40	420	110	1250	90	1000	170	2120
All cancers	330	4100	420	5100	340	3870	560	7030

DISCUSSION

The problem of assessment of the group-specific dose is eliminated if the dose distribution is uniform, but its significance increases with increasing non-uniformity. The problem is closely related to the problems in the definition of the effective dose with respect to the group of remainder organs (1,8,9). The difficulties arising from the definition of the remainder (8,9) may be emphasized if the dose distribution is strongly non-uniform. For example, in CT examinations of the head, the dose to the brain is by far the highest organ dose. The brain is one of the remainder organs, and the interpretation of the definition of the remainder has a strong influence on the effective dose and risk assessment. The goals in the risk assessment of specific groups differ in some respects from the goals in defining the effective dose; it may be appropriate to modify the rules defining the remainder according to the purpose, rather than to apply them literally.

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