RADIATION RISKS TO THE PATIENT IN DIAGNOSTIC RADIOLOGY: AN APPLICATION OF RADIATION DETRIMENT

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Radiation detriment and effective dose equivalent have been introduced as concepts for assessing the health impact of radiation received by more than one tissue from whole or partial body exposures. Radiation detriment can be described on a uniform scale and is a useful concept for assessing patient risk from diagnostic radiology, but the effective dose equivalent cannot be described in a unique way for the same purpose.

Radiation detriment (G) can be defined by the relationship:

$$G = \sum s_T \, r_T \, \bar{D}_T .$$

The quantity $\bar{D}_T$ is the average absorbed dose (cGy)in a given tissue. The quantity r_T is the cumulative lifetime risk of incidence per cGy for a health effect occurring in a particular tissue. The magnitude of each risk depends on the specific tissue that is exposed, and in some circumstances whether the individual is a male or female. In some cases the risk is a function of the age at which an individual was exposed. Because the periods of followup for the populations that are under study are not complete, there are uncertainties in estimating cumulative lifetime risks of incidence. It is likely that the manner in which the risk for each health effect should be projected in time is not the same. In addition, there is considerable difficulty in projecting the dose-response relationship to absorbed doses as low as 1 to 10 cGy.

The factor s_T is the relative severity of the particular health effect induced in the tissue. If one equates radiation detriment to risk of incidence, then s_T would have a value of 1. If one equates radiation detriment to risk of mortality, then s_T would be the fraction of individuals not surviving the health effect for 5 years, or some other agreed upon convention. One could also express radiation detriment as risk of incidence modified by the severity of the health effect or its treatment.

Radiation detriment does not require the use of a linear nonthreshold dose response. Any method can be used to arrive at the values of r_T from observed scientific evidence. However, once r_T has been arrived at for the lower dose region, a proportional relationship is used to compute risks in the range of absorbed dose encountered in diagnostic radiology. This would generally be less than 10 cGy.

If an individual receives a uniform whole body absorbed dose (D_{wb}), then the average absorbed dose $\bar{D}_T$ is equal to D_{wb} for each tissue and the equation can be rewritten as:

$$D_{wb} = \frac{G}{\sum s_T \, r_T} = D_E .$$

This formulation is the effective absorbed dose (D_E) or the effective dose equivalent (H_E) if the radiations have different quality factors. If the sum of the $s_T \, r_T$ components is a constant, then the effective absorbed dose would be unique for a given radiation detriment. If the sum of the $s_T \, r_T$ components is not a constant, then the effective absorbed dose will not be unique.

An example where a single set of values for s_T and r_T have been selected is the set of current ICRP 26 risk factors for genetic and somatic health effects (1). These data apply to a mixed adult population and were intended for use in developing a radiation protection scheme for workers. The ICRP 26 risk factors are equivalent to mortality for cancer and leukemia, and to the incidence of serious hereditary illness for the first two generations of offspring. The sum of the s_T r_T components for these risk factors is 1.65×10^{-4}, and is a constant. Therefore, for any value of radiation detriment the effective absorbed dose is fixed.

An example where the important differences in the values of the cumulative lifetime risks of incidence (r_T) between males and females are recognized is the analysis of Laws and Rosenstein (2). Here, the effective absorbed dose concept was applied to diagnostic radiology for somatic effects. The risk factors are for incidence modified by a relative severity, patterned after the suggestions in ICRP 14 (3). This separation by sex acknowledged that breast cancer occurs mainly in women and that there are observed differences in risks between the sexes for thyroid cancer and leukemia. The sum of the s_T r_T components for the risk factors given in that analysis are 1.8×10^{-4} for the female and 9.9×10^{-5} for the male. Therefore, for the same value of radiation detriment, the effective absorbed dose for the male is 1.8 times that for the female.

This example is still a relatively simple one because only one major difference occurred, the presence of the female breast. The situation becomes more complex when one considers all the somatic and genetic health effects of importance. A more complete example is for the cumulative lifetime risks of incidence of various health effects for an average adult female. The relative severity is now 1. However, the female can be feritle or non-fertile, or she can be pregnant at the time of exposure. Table 1 gives illustrative risks for various cancers in the exposed adult (derived from the 1980 BEIR report)(4), for genetic illness in offspring of the exposed adult (from ICRP 26)(1), and for two somatic effects expressed in the child exposed *in utero* (from the 1980 BEIR and the 1977 UNSCEAR reports)(4,5).

Table 1. Cumulative Lifetime Risks of Incidence for Health Effects (Average Adult Female)

Health Effect	r_T (per cGy) $\times 10^{-4}$ Non-Fertile	Fertile	Pregnant
Breast Cancer	1.2	1.2	1.2
Leukemia	0.18	0.18	0.18
Lung Cancer	0.75	0.75	0.75
Thyroid Cancer	1.2	1.2	1.2
Other Cancers	1.5	1.5	1.5
Genetic Illness		2.0	2.0
Childhood Cancer			5.0
Congenital Effects			10.0
$\Sigma s_T r_T$ ($s_T = 1$)	4.8	6.8	21.8

Using these data, the sums of the s_T r_T components ($s_T = 1$) are 4.8×10^{-4} for the non-fertile female, 6.8×10^{-4} for the fertile female and 21.8×10^{-4} for the pregnant female. Therefore, for the same value of radiation detriment, the effective absorbed dose would be significantly different for each. For the non-fertile female it would be 4.5 times greater than that for the pregnant female. For the fertile female it would be 3.2 times that for the pregnant female. Therefore, it is not possible to establish the effective absorbed dose in a unique fashion.

However, radiation detriment is a useful concept which can be described on a uniform scale. With a consistent set of cumulative lifetime risks of incidence, radiation detriments for diagnostic x-ray exams can give a valuable perspective. Using the risks for the average adult female as an example, Table 2 gives the relative radiation detriment for some common radiographic x-ray exams. In Table 2 the relative radiation detriment is normalized to a value of 1 for that entry with the largest radiation detriment, which has a value of 1.43×10^{-3}. This is the cumulative lifetime risk of incidence for all the health effects applicable to a pregnant female (and unborn child) that underwent a typical barium enema exam, consisting only of the radiographic portion. Note the differences for the lumbar spine and the barium enema examinations as the status of the female changes.

Table 2. Relative Radiation Detriment Considering Various Health Effects - Average Adult Female (a)(b)

Exam	Somatic (Non-fertile Female)	Somatic & Genetic (Fertile Female)	Somatic, Genetic & In Utero (Pregnant, Fertile Female)
Chest	0.003	0.003	0.003
Thoracic Spine	0.05	0.05	0.05
Lumbar Spine	0.04	0.09	0.52
Barium Enema	0.05	0.15	1.00
Mammography (Xerox)	0.06	0.06	0.06
Mammography(Film/Screen)	0.02	0.02	0.02

(a) r_T from BEIR, ICRP and UNSCEAR; $s_T = 1$
(b) a relative radiation detriment of 1.00 corresponds to a radiation detriment of 1.43×10^{-3} (incidence)

For the purpose of presenting risks to the individual patient, an array of the cumulative lifetime risks of incidence that make up the radiation detriment would be the most meaningful. This would lead naturally to a discussion of the seriousness of any of the particular health effects. The following example for a barium enema exam for an adult female is illustrative. Assuming a typical radiographic exam of 4 films, the significant absorbed doses are 0.3 cGy for the active bone marrow, 0.05 cGy for the lungs, 0.4 cGy for other organs in the abdominal region, and 0.8 cGy for the ovaries and uterus (6). In Table 3 are displayed the cumulative lifetime risks of incidence for the corresponding health effects due to radiation, as well as the risks from natural causes. In this case, the risks of childhood cancer or congenital anomalies to the unborn child are the most notable. However, none of the radiation risks approach the natural risks for the same health effect. This kind of display places in perspective the radiation risk to the patient and would be very useful in a clinical setting.

Table 3. Array of Radiation Risks - Barium Enema (Radiographic), Pregnant Adult Female

Health Effect	Tissue Dose (cGy)	Cumulative Lifetime Risk of Incidence (Radiation)	Natural Lifetime Incidence
Leukemia	0.3	1 in 185,000	1 in 125
Lung Cancer	0.05	1 in 267,000	1 in 43
Other Cancers	0.4	1 in 16,700	1 in 4(a)
Genetic Illness	0.8	1 in 6,250	1 in 10
Childhood Cancer	0.8	1 in 2,500	1 in 540
Congenital Effects	0.8	1 in 1,250	1 in 25

(a) All cancers

The task is to develop an authoritative set of cumulative lifetime risks of incidence for the various health effects. Based upon data that are currently available, it appears that a provisional set with the characteristics identified in Table 4 could be developed. This collection would include separate values for genetic illness due to exposure of the the reproductive organs of fertile males and females. It would also include appropriate values for breast cancer in females for various ages at exposure. Values for other cancers would be listed separately, and where significant, would be a function of age and sex. Values for in utero exposures both for childhood cancer and congenital malformations would be necessary for the unborn child, perhaps further defined by trimester of pregnancy. It's time to recognize that different individuals are at different risk, particularly when applying risk concepts to patients in diagnostic radiology. The practice of using general statements is misleading.

Table 4. Desirable Array of Cumulative Lifetime Risks of Incidence for Various Health Effects

	MALE			FEMALE		
Health Effect	Child	Adult	Older Adult	Child	Adult	Older Adult
Genetic Illness		(a)			(a)	
Breast Cancer				(b)	(b)	(b)
Other Cancers	(c)	(c)	(c)	(c)	(c)	(c)
Childhood Cancer					(d)	
Congenital Effects					(d)	

(a) If fertile
(b) By appropriate age categories
(c) Each cancer and leukemia listed separately; by appropriate age categories
(d) If pregnant and by trimester

REFERENCES

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(6) Kereiakes, J.G. and Rosenstein, M. Handbook of Radiation Doses in Nuclear Medicine and Diagnostic X Ray. CRC Press, Inc., Boca Raton (1980)