BENEFITS OF THE EFFECTIVE DOSE EQUIVALENT CONCEPT AT A MEDICAL CENTER

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ABSTRACT

A primary objective of the recommendations of the International Committee on Radiological Protection Publication 26 is to insure that no source of radiation exposure is unjustified in relation to its benefits. This objective is consistent with goals of the Radiation Safety Committee and Institutional Review Board at medical centers where research may involve radiation exposure of human subjects. The effective dose equivalent concept facilitates evaluation of risk by those who have little or no knowledge of quantities or biological effects of radiation. This paper presents effective dose equivalent data used by radiation workers and those who evaluate human research protocols as these data relate to personal dosimeter reading, entrance skin exposure, and target organ dose. The benefits of using effective dose equivalent to evaluate risk of medical radiation environments and research protocols are also described.

INTRODUCTION

Radiation plays an important role in the diagnosis and treatment of various diseases and in biomedical research. Risk to patients from radiation exposures are low and easily justified in relation to their benefits. While it is assumed that an increased risk of stochastic effects is associated with radiation exposure of patients, the benefits in terms of quality and quantity of life far outweigh these risks. The benefits to individuals who receive radiation exposure as a result of their occupational activities or participation in research protocols are more or less limited to financial compensation or altruistic rewards. Consequently, for these last two categories greater emphasis is placed upon the risk element of the benefit versus risk equation, and greater effort is expended in keeping such exposures as low as reasonably achievable. Since the benefit members of the public derive from coincidental radiation exposure as a result of visiting a medical facility is negligible, care is taken to see that such exposures are also negligible.

This paper discusses advantages that the effective dose equivalent concept provides in discussions of risk versus benefit with patients or their families, individuals who receive occupational radiation exposure, committee members who evaluate risk to human subjects in research protocols, and participants in research protocols that utilize radiation.

SOURCES OF RADIATION EXPOSURE

Clinical

Radiation exposure of patients for treatment of benign or malignant conditions provides obvious palliative or curative benefits. Risks are usually discussed in terms of deterministic (nonstochastic) effects associated with localized high doses of radiation and relative probabilities of stochastic effects that may manifest themselves in subsequent years. While efforts are made to minimize radiation doses to tissues free of disease, radiation dose to treated tissues is dictated by clinical experience and desired outcome.

Occasionally, patients who receive low doses of radiation from diagnostic radiology or nuclear medicine become concerned with the risk associated with such exposure. Lay publications often use the entrance skin exposure from a radiographic procedure to compare with natural background radiation, occupational radiation exposure limits, or some other source of radiation exposure the public may have experienced. Since radiation associated with radiographic examinations is localized and is significantly attenuated by overlying tissues and organs, exposures are nonuniform and cannot be compared to other sources of radiation exposure by a simple, easily measured quantity such as entrance skin exposure. Likewise, for diagnostic nuclear medicine procedures use of the radiation dose to a single organ results in an oversimplified expression of radiation risk.

While the effective dose equivalent as defined by the International Commission on Radiological Protection (1977) is based on risk factors for an average human (no distinction for age, sex, or ethnic factors), it provides a much more reasonable basis for estimation of risk and comparison of various procedures for which the radiation exposure may not be the same. Values for effective dose equivalent can be used with reasonable confidence to compare a particular procedure to one that is familiar to the patient.

The effective dose equivalents from selected radiographic and nuclear medicine examinations are shown in Tables 1 and 2. For purposes of these comparisons, risk to male breast was assumed to be negligible, and differential doses to male and female gonads were utilized to provide effective dose equivalent for male and female. The difference between skin dose and effective dose equivalent for various radiographic examinations is particularly notable.

Occupational

For employees who receive external radiation exposure from the use of gamma emitting radionuclides, the external radiation monitor provides a reasonable estimate of effective dose equivalent. Recommendations for radiation safety practices to reduce risk can be based to a large extent on the external monitor reading. For employees in diagnostic radiology, the external monitor reading can be used as an indicator of external exposure, but it often is not a good estimate of effective dose equivalent. While this reading can be used as a indicator of the adequacy of radiation safety practices in the x-ray facility, it often cannot be used to quantify risk to employees, particularly those in special procedures rooms where the use of lead aprons is required.

It is common practice, and in some states it is required, to wear the external monitor on the outside of lead aprons when only one monitor is provided. Even when the external monitor readings are lower than the maximum permissible dose equivalent or the investigational level for a radiation worker, they may be a source of anxiety, particularly for new employees or those who plan to raise children and are concerned about possible genetic effects. While it is comforting for them to know that the lead apron absorbs more than 90% of the incident photons, use of effective dose equivalent provides them with an additional quantity that can be used to compare their occupational exposures to those from other occupational exposure categories. Table 3 shows the external monitor reading and estimated effective dose equivalent for several occupational exposure categories at Mayo Clinic.

No guidance has been provided by the National Council on Radiation Protection and Measurements (NCRP) on a procedure to estimate effective dose equivalent from external monitor readings. Faulkner and Harrison (1988) and Webster (1989) have suggested correction factors that may be applied to external radiation monitors worn outside or under lead aprons. Meinhold (1989) has suggested that the calculation of effective dose equivalent should be based on a knowledge of the ratio of the radiation exposure under the apron to that received to tissues outside the apron together with the guidance given in NCRP Report No. 91 (1987). Meinhold's suggestion allows flexibility in positioning of external monitors provided the computation of effective dose equivalent is based on data appropriate to position of monitors and thickness of lead aprons. This should facilitate the computation of reliable effective dose equivalents that can be compared among facilities and can be used to reduce anxiety among employees in radiographic facilities. Further guidance is required to assure accurate estimates of effective dose equivalent from nonuniform external radiation exposure.

Research

Exposure of human research subjects to sources of radiation in the course of scientific investigation involves several considerations that may override those normally applied to clinical workups. Research protocols must be evaluated by a Committee on Use of Human Subjects (e.g. Institutional Review Board, Bioethics Committee, or Radiation Safety Committee) to assure protection of human research subjects. The Committee must be convinced that the use of radiation is necessary to carry out the study and that every effort has been made to minimize radiation dose to subjects, including limiting the number of subjects to those required to obtain statistical significance. Also, research subjects must be provided meaningful information on risk so they can decide if they want to participate.

Members of the Committee may have very little background on the risks and potential biological effects of radiation. They often depend on assistance from radiation safety staff, radiologists, or radiation oncologists to determine whether the risks associated with the radiation exposure as a result of participating in the investigation are acceptable. While federal regulations do not prescribe dose equivalent limits for human research protocols, there is usually an attempt to apply the recommended maximum exposure limits for members of the

general public to these protocols. Higher radiation exposures are often allowed to subjects inflicted with the disease under study, but it is assumed that no benefit other than altruistic fulfillment is derived from participation in such a protocol. Since it is assumed that there is no benefit to the patient, the Committee is interested in quantifying and minimizing risks to the maximum extent possible.

Effective dose equivalent provides a means for evaluation of radiation risk from all types of investigations that involve radiation exposure of research subjects. This is especially helpful in the evaluation of new technologies where the Committee has no prior knowledge or experience. The use of entrance skin exposure for evaluation of risk in protocols that utilize radiographic examinations often erroneously implies a higher level of risk as compared to the whole-body dose from diagnostic nuclear medicine examinations. For example, the skin dose is approximately 20 times the estimated effective dose equivalent (Table 1) for fast CT (a cardiology procedure). However, the effective dose equivalent for fast CT is only one-third that for a radionuclide ventriculogram that uses Tl-201 (Table 2). While some members of the Committee may be familiar with radiographic and nuclear medicine examinations, they may be totally unfamiliar with the radiation doses to subjects who participate in metabolic studies. The use of effective dose equivalent for metabolic applications (Table 2) can be compared not only to the general limits on radiation exposure to members of the public, but to effective dose equivalents from the more familiar nuclear medicine examinations.

CONCLUSIONS

The concept of effective dose equivalent was derived with the intent of prospectively examining risk associated with a given level of occupational radiation exposure (ICRP 1977). The recommended occupational exposure limits of the ICRP are set at a level believed to be associated with a low degree of risk. Therefore, unless these limits are exceeded by a considerable amount, the risk is sufficiently low to not warrant costly measures to reduce risk. It has become common to apply the effective dose equivalent concept to exposure categories other than occupational, including radiation exposure of patients and research subjects.

The effective dose equivalent provides a meaningful method for adding internal and external radiation exposures. It also provides a method for communicating risk to patients, research subjects, and members of committees and for placing on a common scale, radiation exposures from a variety of sources.

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Table 1. H_e for Radiographic Examinations

Procedure	Skin Dose[a] (mGy)	Organ Dose (mGy)								H_e(mSv)	
		OV	TE	BR	BS	LU	RM	THY	Trunk[b,c]	M	F
Knee	0.3	---[d]	---	---	---	---	---	---	---	---	---
Abdomen	2	0.5	---	---	0.1	---	0.1	---	0.3	0.2	0.2
Abdomen CT	46.5	1.5	1.5	---	0.4	1.5	3.3	---	25.0	8.4	8.4
Chest (PA)	0.2	---	---	---	---	0.1	---	---	---	---	---
Fast CT (chest)	93	0.7	0.7	15.0	8.0	12.6	8.0	7.0	0.7	5.6	5.6
Chest CT	37.2	0.3	0.3	36.0	4.4	12.4	4.4	2.8	0.3	7.8	7.8
Coronary Angiogram	275	0.3	0.2	11.1	3.0	103	19.2	8.2	44.3	30.0	30.0
Mammogram	3.9	---	---	0.7	---	---	---	---	---	---	---
Head CT	32.5	---	---	0.1	2.1	---	2.1	1.4	0.1	0.4	0.4

[a] 1 R ESE = 9.3 mGy skin dose

[b] As defined in Rosenstein (1988)

[c] A weighting factor of 0.30 has been multiplied by the trunk absorbed dose value to calculate effective dose

[d] --- = less than 0.1 mGy

Table 2. H_e for Radiopharmaceuticals

Radiopharmaceutical		Activity (kBq)	Organ Dose (mGy)													H_e(mSv)	
			OV	TE	BR	RM	LU	THY	BS	Other (5 highest doses)					TB	M	F
Cardiology Applications																	
Tc-99m	Erythrocytes	1110	4.7	3.0	4.8	8.1	15.5	5.4	1.0	16.7	11.1	9.7	8.3	6.9	4.1	9.2	9.6
Tc-99m	PYP	740	2.6	1.8	0.7	7.1	1.0	0.7	4.7	5.4	3.7	2.8	1.7	1.5	1.4	5.8	6.0
Tl-201	Chloride	150	18.8	20.8	---	---	---	25.6	---	48.0	22.8	20.0	10.0	16.0	8.4	16.8	16.3
Tc-99m	RP-30A	1110	0.6	0.6	---	---	3.0	13.5	---	28.8	18.0	15.0	9.9	13.5	0.6	6.2	6.2
General Applications																	
In-111	Oxine	2	7.4	0.5	—	1.7	---	---	---	34.9	19.5	8.9	2.8	0.9	1.0	4.7	6.4
Tc-99m	HMPAO	740	4.6	1.4	—	2.6	---	20.0	---	26.0	16.0	10.8	10.8	9.4	2.6	8.2	9.0
Tc-99m	DMSA	111	0.4	0.2	0.2	0.7	0.3	0.1	0.4	18.9	2.1	1.4	1.4	1.1	0.3	1.7	1.8
I-131	MIBG	2	1.2	1.1	1.3	1.2	3.5	0.9	1.1	15.4	10.9	9.1	4.3	3.1	1.1	3.7	3.7
Metabolic Applications																	
H-3	Glucose	7	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.25	0.14	0.14	0.14	0.14	0.14	0.15	0.15
C-14	Palmitate	7	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.48	0.10	0.10	0.10	0.10	0.10	0.12	0.12
C-14	Bicarbonate	30	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
H-3	Triolein	7	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.16	0.39	0.02	0.02	0.05	0.05

Table 3. Annual H_e (mSv) for Employee Categories[a]

Category	Maximum		Mean	
	Badge	H_e	Badge	H_e
General Radiographer[b]	20	1.6	1.2	0.1
Cardiac Lab Cardiologist[c]	40	1.6	8.5	0.3
Nuclear Medicine Technologist	20	20	0.8	0.8

[a] For purposes of this comparison, it has been assumed that attenuation through the body is negligible.

[b] Wears 0.25 mm lead apron, 8% transmission at 80 kVp.

[c] Wears 0.5 mm lead apron, 4% transmission at 120 kVp.