# Application of the Effective Dose Equivalent to Nuclear Medicine Patients

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Recently, a number of articles have appeared in the literature in which calculations of the dose to tissues of the body have been expressed in terms of the "effective dose equivalent." This editorial reviews the foundations of this new approach and its limitations and concludes with a statement from the Medical Internal Radiation Dose (MIRD) Committee that the use of the effective dose equivalent, as defined in ICRP Publication 26, was intended for occupational exposure and is inappropriate in dose calculations associated with nuclear medicine patients.

In 1977, the International Commission on Radiological Protection (ICRP) published a major revision to their recommendations on radiation protection in the work place (*1*). In this document, the Commission introduced the terms "stochastic" and "nonstochastic" effects of radiation and set annual radiation exposure limits for both. A stochastic effect is an effect for which the *probability* of the effect occurring is a function of dose, without threshold. A nonstochastic effect is an effect for which the severity of the effect is a function of dose and therefore a threshold may exist. More recently, the ICRP has recommended the word "deterministic" be used instead of nonstochastic (*2*).

The ICRP approach was to set an annual occupational radiation exposure limit such that the probability of stochastic effects occurring was considered acceptable and to set a second limit for deterministic effects that would prevent these effects from occurring, even if the exposure occurred at this limit for the working lifetime of the individual. In the dose range encountered in radiation protection, the Commission assumed that the major stochastic effects were carcinogenesis and mutagenesis. Deterministic effects were considered to be "threshold" or "pseudo-threshold" in nature and included effects such as nonmalignant damage to the skin, cataract of the lens and cell depletion in the bone marrow causing hematological deficiencies (*1*).

The Commission specified that the dose limitation for stochastic effects should be based on the sum of the weighted dose equivalents to individual tissues of the body and recommended a set of tissue-weighting factors for this purpose. In addition, the ICRP stated that the annual limit for stochastic effects be applied to the *sum* of the external and internal exposures (*1*). Later, at their 1978 Stockholm meeting, the ICRP assigned the term *effective dose equivalent* and the symbol $H_E$ to this new concept (*3*). The ICRP explained the intent of the effective dose equivalent when it stated: "For stochastic effects the Commission's recommended dose limitation is based on the principle that the risk should be equal whether the whole body is irradiated uniformly or whether there is non-uniform irradiation" (*1*).

The effective dose equivalent and the use of tissue-weighting factors ($w_T$) was a major portion of the ICRP system based on risk. A second important facet of this new risk-based system for radiation protection was the stated goal that occupationally exposed workers should be at approximately the same risk as workers in other "safe" industries who were not exposed to radiation in the workplace.

Each tissue-weighting factor was determined by taking the ratio of the risk for a particular tissue and the total risk for all tissues in the body. To determine the appropriate tissue-weighting factors, the Commission evaluated the risk per unit dose equivalent (risk per sievert) for the induction of a *fatal* cancer or for producing an hereditary effect that could be expressed in the next two generations. Fatal cancers were chosen because it was possible to compare the risk of inducing a fatal cancer with the risk of a work-related death in a safe industry (about $10^{-4}$ per year). The tissue-weighting factors were based on assigning a risk per unit dose equivalent for selected tissues of the body but were modified to take into account the "essentialness" of the organ to the well-being of the individual and the extent to which the induced effect was "treatable." That is, in some cases, tissues with high

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radiosensitivity were assigned low weighting factors because the cancer was assumed to be induced in an unimportant tissue and/or the induced cancer was easily treated (i.e., survivable), as is the case with most thyroid cancers.

The approach to determining these weighting factors has been described (*4*). However, it is important to point out certain aspects of the approach taken by the Commission in selecting the values of risk coefficients used to calculate the weighting factors that make its use inappropriate in nuclear medicine patients. First, the effective dose equivalent is intended for radiation protection purposes. Risks are compared to mortality in safe industries and do not include an evaluation of the total risk to the general population, loss of income, the cost of ill health, the social impact of the induced effect, etc.

Second, the risk coefficients assigned to individual tissues (and, thus, the tissue-weighting factors) were assumed to be independent of the age and sex of the exposed individual. The intent was to focus on *occupationally exposed adults* only. Even though the age range of interest was 20 to 60 years and both sexes were considered, the risk coefficients and the total risk were assumed to be constants.

Third, the number of tissues considered by the Commission in the 1977 recommendations was limited to six, with all other tissues lumped into a category called the "remainder." Five of the six tissues were considered important for the induction of cancer (female breast, lung, red bone marrow, thyroid and cells on bone surfaces). The sixth tissue included both the male and female gonads and only hereditary effects over the next two generations were considered. The remaining tissues were assigned a single risk coefficient and a weighting factor was calculated based on the combined risk of inducing a fatal cancer in these unnamed tissues. The Commission established an upper bound for stochastic effects in the remaining tissues by comparing these effects to the induction of leukemia. In addition, the Commission stated that "... it is further assumed that no single tissue is responsible for more than one-fifth of this value" (*1*).

Fourth, each risk coefficient was represented by a single value (sometimes for acute exposure) selected from a wide range of published values. The risk coefficient for a given tissue may vary by nearly an order of magnitude and, in many cases, may depend on age, sex, dose, dose rate, dose protraction and other factors (*5*). More recent evaluations of the literature by the ICRP have resulted in a revised and expanded set of tissue-weighting factors (*2*). However, these new tissue-weighting factors have not been adopted by the regulatory bodies in the United States. Instead, the weighting factors found in ICRP Publication 26 are recommended in the most recent federal regulations on radiation protection (*6*). There is no federal requirement for the assessment of effective dose equivalent for individuals undergoing diagnostic or therapeutic procedures involving ionizing radiation.

The Commission also discussed medical exposure in its 1977 recommendations. Here, the discussion focused on justification of the exposure, balancing the benefits and the risks, consideration of alternatives, etc. However, the Commission gave little guidance on the use of the effective dose equivalent as an indication of risk in medical exposures associated with diagnostic or therapeutic uses of radiation. Their position summarized in paragraph 92 (*1*) is as follows:

> "Medical exposure is, in general, subject to most of the Commission's system of dose limitation, that is: unnecessary exposures should be avoided; necessary exposures should be justifiable in terms of benefits that would not otherwise have been received; and the doses actually administered should be limited to the minimum amount consistent with the medical benefit to the individual patient. The individual receiving the exposure is himself the direct recipient of the benefit resulting from the procedure. For this reason, it is not appropriate to apply the quantitative values of the Commission's recommended dose-equivalent limits to medical exposures. With certain medical exposures, a very much higher level of risk may in fact be justified by the benefit derived than by the level judged by the Commission to be appropriate for occupational exposure or for exposure of members of the public."

The Commission provided additional explanation in paragraph 107 (*1*):

> "The values of $w_T$ ... are intended as guidance for those concerned with calculating secondary and derived limits.... In particular, they are used ... in calculating values of annual limits on intake (ALI) for radionuclides, which take account of the dose equivalent in each tissue."

Based on the above considerations, the MIRD Committee has concluded that, while the use of effective dose equivalent may well be appropriate for group considerations such as radiation protection for occupationally exposed groups of workers (including those in nuclear medicine) and volunteers entering investigational protocols, *it is inappropriate to use the effective dose equivalent for individual patients undergoing nuclear medicine procedures*. Age, sex and dose rate are exceedingly important for individual risk estimates and an underlying illness can have an enormous effect on these risks. The effective dose equivalent has no real meaning in the practice of nuclear medicine because the risk coefficients are not applicable directly to the medical situation and, in its formulation, no consideration was given to the potential benefits of the diagnostic or therapeutic procedure. Therefore, the MIRD Committee recommends that dose

calculations for patients undergoing nuclear medicine procedures continue to be made in terms of the radiation absorbed dose (in units of grays or rads).

## REFERENCES


1. International Commission on Radiological Protection. Recommendations of the ICRP, ICRP Publication 26. *Annals of the ICRP, volume 1, no. 3.* Oxford: Pergamon Press; 1977.
2. International Commission on Radiological Protection. Recommendations of the ICRP. ICRP publication 60. *Annals of the ICRP, volume 21, no. 1–3.* Oxford: Pergamon Press; 1991.
3. International Commission on Radiological Protection. Statement from the 1978 Stockholm meeting of the International Commission on Radiological Protection, 1978.
4. International Commission on Radiological Protection. Problems involved in developing an index of harm. ICRP Publication 27. *Annals of the ICRP, volume 1, no. 4.* Oxford: Pergamon Press; 1977.
5. Pochin EE. Why be quantitative about radiation risk estimates? Lauriston S. Taylor Lecture Series in Radiation Protection and Measurements, National Council on Radiation Protection and Measurements, Bethesda, MD, March 15, 1978.
6. Title 10 Code of Federal Regulations Part 20. U.S. Nuclear Regulatory Commission, Washington, DC, May 21, 1991.


*(continued from page 713)*

# SELF-STUDY TEST

# Gastrointestinal Nuclear Medicine

**ANSWERS** *(continued)*

**Items 12-15: Red Blood Cell Labeling with $^{99m}$Tc**

Answers:12, F; 13, F; 14, T; 15, F

In vivo red blood cell labeling is the most frequently utilized method because it is the simplest approach. It is not the most satisfactory method, however, for gastrointestinal bleeding scintigraphy. Because of the variability in labeling efficiency, significant amounts of unbound, free $^{99m}$Tc can be secreted into the stomach and bowel, causing false-positive studies. Additionally, much of the activity not bound to red blood cells is excreted by the kidney as labeled small proteins and reduced technetium complexes. This urinary activity may cause problems in interpretation e.g., a rectal bleeding site may be obscured and renders the bladder as the critical organ with this labeling method approximately 2.4 rads/20 mCi. When in vivo techniques are used, the "cold" stannous pyrophosphate should be injected directly into a vein. The precise reason for this is unclear, but if the cold pyrophosphate is injected via an indwelling catheter, poor red blood cell labeling can occur, and this may result in a nondiagnostic examination.

The basic theory underlying red blood cell labeling with $^{99m}$Tc is as follows. The stannous ion complex freely diffuses into the red blood cell and binds to cellular components. Pertechnetate ion also freely diffuses into and out of red cells. Once the pertechnetate ion is inside the red blood cell, the stannous ion ($Sn^{2+}$) reduces it, and the reduced technetium species binds to hemoglobin. Once bound, it remains intracellular. If any stannous ion is present outside the red blood cell, any free extracellular pertechnetate will be reduced. This free reduced technetium will degrade the images (increased background activity and increased urinary excretion).

The in vitro method provides the optimal red blood cell labeling, because of its uniformly high labeling efficiency. The most recent modification of the in vitro method uses whole blood and does not require centrifugation or the removal of blood into multiple sterile containers. The Brookhaven-modified red blood cell labeling kit achieves high labeling efficiency by stopping the premature extracellular reduction of $^{99m}$Tc pertechnetate. By the addition of an oxidizing agent sodium hypochlorite, which cannot pass through the red-blood cell membrane, extracellular stannous ion is oxidized to stannic ion ($Sn^{4+}$). This prevents extra cellular reduction of pertechnetate ion.

The modified in vivo ("in vivtro") technique of red blood cell labeling has been developed as a compromise between the in vivo method and the original in vitro method (which required a long incubation period, multiple handling steps, and written patient consent, because of its investigational status.) When the "in vivtro" technique is used, heparin is often used as the anticoagulant. Unfortunately, $^{99m}$Tc heparin complexes can be excreted in the urine and accumulated in the bladder. For this reason, some investigators recommend that ACD solution be used as the anticoagulant, which yields a slightly higher labeling efficiency and reduced urinary activity.

**References**


1. Porter WC, Dees SM, Freitas JE, Dworkin HJ. Acid-citrate-dextrose compared with heparin in the preparation of in vivo/in vitro technetium-99m red blood cells. *J Nucl Med* 1983;24:383-387.
2. Srivastava SC, Chervu LR. Radionuclide-labeled red blood cells: current status and future prospects. *Semin Nucl Med* 1984;14:6882.


For further in-depth information, refer to the syllabus pages in Nuclear Medicine Self-Study I.