Radiation Dosimetry in Radionuclide Hysterosalpingography with Technetium-99m

TO THE EDITOR: Two recently published papers have addressed the question of radiation dosimetry concerns in radionuclide hysterosalpingography with technetium-99m (^{99m}Tc) microspheres or pertechnetate (*1,2*). The estimates of the radiation dose to the ovaries, which is the principal target organ of concern, differ substantially because of the different assumptions which supported the estimates. In this letter, I will examine these differences and draw some conclusions about the range of dose estimates which might reasonably be expected from this procedure.

McCalley et al. (*1*) presented radiation dose estimates for the ovaries. These estimates were provided from our center, and were based on assumptions given in a presentation to the Society of Nuclear Medicine by Egbert et al. (*3*). Hyznar et al. (*2*) presented radiation dose estimates based on their own measurements and calculations. It should be noted that Hyznar et al. administered [^{99m}Tc]pertechnetate, while McCalley et al. administered ^{99m}Tc-labeled microspheres [as did Egbert et al. (*3*)].

The assumptions we used to provide the estimates to McCalley et al. were that 15% of the injected activity went to the ovaries, 65% went to the uterus and fallopian tubes, and the remaining 20% remained in the vagina. Because serial counts over these regions of interest at 30 and 60 min showed no decrease in activity, the activity was assumed to be removed only by physical decay. The MIRD phantom (*4*) has no source regions representing the uterus, fallopian tubes, or vagina; we therefore used some approximations that would provide reasonable estimates of the dose from activity in these areas. Reciprocity (*5*) was used to estimate the dose to the ovaries from activity in the uterus and fallopian tubes (assuming that activity in the fallopian tubes was in the uterus). The urinary bladder was used to model activity in the vagina because of the similarity in position. These two approximations are not very important to the total dose to the ovaries because most of the radiation dose is from self-irradiation. The total dose to the ovaries using these assumptions is 1.5 mGy/MBq (the estimate was incorrectly quoted in the article (*1*) as 0.75 mGy/MBq to *each* ovary).

Hyznar et al. (*2*) assumed that only 3% of the injected activity reached the ovaries for estimating the ovarian self-dose. In estimating the dose from the uterus, they assumed that 100% of the administered activity was in the uterus. They measured the effective half-time for the ^{99m}Tc in the entire region to be 50 min. Using these assumptions, they estimated the dose to the ovaries from activity uniformly distributed throughout the ovaries to be 0.048 mGy/MBq, which is about a factor of 30 lower than the value we calculated (the activity is a factor of 5 lower and the effective half-time is a factor of ~7 lower).

If the activity remains on the ovarian surface, and is not taken up by the ovaries, we have a much different dosimetry situation. Hyznar et al. (*2*) estimated the dose to the tunica albuginea (the thin layer of connective tissue that forms a layer over the ovaries) by approximating the dose to the thin ellipsoidal layer on the surface of the ovaries corresponding to the maximum range of the ^{99m}Tc electrons (0.2 mm). The ovaries in the adult female have been described for dosimetry purposes as ellipsoids with half-axes of 1.17, 0.58, and 1.8 cm (*6*). The volume of each ovary is 5.1 g; the volume of a thin layer of 0.02 cm thickness on the surface of one ovary would be ~0.32 g (the total target mass on both ovaries would be 0.64 g). If all of the electron energy from ^{99m}Tc were absorbed in this thin layer, the absorbed dose would be ~20 mGy/MBq to the thin layer, assuming 15% uptake and a 6-hr effective half-time and ~0.55 mGy/MBq assuming 3% uptake and a 50-min effective half-time. The radiation dose would not be uniform throughout the layer, but would drop in an approximately exponential fashion from the surface of the ovaries to the maximum range of the electrons. Therefore, some areas would receive a higher radiation dose than 20 mGy/MBq, and most areas would receive a lower dose. The ovarian follicles and the germinal epithelium, however, would receive no dose from the electrons because they are more than 0.2 mm below the surface. The photon dose from activity on the surface of the ovaries cannot be easily calculated, but would be less than the photon dose from activity uniformly distributed throughout the ovaries. This latter quantity can be calculated by subtracting the electron component from the self-irradiation S-value (*7*). The estimated photon dose would be 0.32 mGy/MBq for 15% uptake and a 6-hr effective half-time and 0.015 mGy/MBq for 3% uptake and a 50-min effective half-time.

The major uncertainties in the estimates derived from this analysis are in: (a) the fraction of administered activity in or on the ovaries; (b) the effective half-time of the activity in the region; and (c) the location of the activity (inside or on the surface of the ovaries).

The differences in the fractional uptake may be attributable to uncertainties in the definition of regions of interest or uncertainties in calibration, or may reflect real differences in the uptake of the two compounds. A faster removal half-time for pertechnetate than for microspheres would not be an unexpected finding. A third, independent study using both compounds would help to determine whether or not a difference in half-time exists.

The question of whether or not the activity is distributed throughout or only on the surfaces of the ovaries cannot be easily resolved through measurements. Animal experiments could add some information. The microspheres are not likely to be distributed throughout the ovaries, because the arteries feeding the ovaries are not involved. Pertechnetate, however, has fairly high mobility in biologic tissues, showing an ability to cross the placenta in animals (*8*) and appear in human breast milk after injection into the bloodstream (*9*). Therefore, it might diffuse into ovarian tissues without involvement of the blood vessels. Until this question is resolved, the conservative assumption that the material is distributed throughout the ovaries should probably be used.

Table 1 summarizes the radiation doses to the ovaries that would be predicted from these various assumptions. The extreme values are different by two orders of magnitude, showing the importance of the underlying assumptions. Much

TABLE 1
Variation in Ovarian Radiation Dose Depending on Location of Activity, Fractional Uptake (f), and Effective Half-Time (t)

	$f = 0.15, t = 6$ hr	$f = 0.03, t = 0.83$ hr
Activity in ovaries	1.5 mGy/MBq	0.048 mGy/MBq
Activity on surface of ovaries	0.32 mGy/MBq	0.015 mGy/MBq

more variation is due to the kinetic model (factor of 20 to 30), however, than to whether the activity is in or on the ovaries (factor of 3 to 5).

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Disparity in Organ Masses Associated with MIRD "S" Factors

TO THE EDITOR: Since the mid-1970s, the nuclear medicine community has relied upon the relatively simple MIRD method for calculation of absorbed doses. MIRD Pamphlet No. 11 describes the formulation of "S" factors based on an anatomic phantom in which "the masses assumed for the organs and tissues of the body are given in Table 1" (*1*).

"S" (absorbed dose per unit cumulated activity) is defined as

$$S(r_k \leftarrow r_h) = \sum_i \frac{\Delta_i \phi_i r_k \leftarrow r_h}{m_k}$$

WHERE Δ = equilibrium dose constant,

ϕ = absorbed fraction, and

m = organ mass.

For self irradiation from particulate emissions, $\phi = 1$, so the equation can be simplified to

$$S(r_k \leftarrow r_k) = \sum_i \frac{\Delta_i}{m_k}.$$

Hence, for pure beta-emitting radionuclides (i.e., no photon emissions so $\phi = 1$), the organ mass that was originally used in the determination of the "S" factor can be calculated by

$$m_k = \frac{\Delta}{S(r_k \leftarrow r_k)}.$$

The organ masses associated with "S" factors for each of the pure beta-emitting radionuclides listed in MIRD Pamphlet No. 10 (viz., ^{3}H, ^{14}C, ^{32}P, ^{35}S, ^{45}Ca, ^{90}Sr, and ^{90}Y) were calculated in this way. "S" factors were taken from MIRD Pamphlet No. 11 (*1*) and Δ values were taken from MIRD Pamphlet No. 10 (*2*). Organs with walls (i.e., GI tract and bladder), skin, bone, and uterus were not included. The organ masses thus obtained are listed in Table 1 along with the respective organ masses listed for the MIRD phantom (*1*).

Organ masses associated with "S" factors for liver, lungs, muscle, thyroid, and total body are in agreement with those listed for the MIRD phantom. For adrenals, kidneys, ovaries, pancreas, spleen, and testes, however, it is obvious that organ masses associated with "S" factors are equivalent to those described for the ICRP "reference man" (*3*) instead of those listed for the MIRD phantom.

The organ mass associated with "S" factors for the red marrow appears to be variable. Although MIRD Pamphlet No. 11 describes the special case of absorbed dose to the red marrow from a particle emitter deposited in the bone, self-irradiation of the red marrow is not explicitly discussed. It can be reasoned, however, that a fraction of energetic particles may escape from the marrow; thus, the absorbed fraction would be <1.0. Examination of Table 1 demonstrates that the red marrow mass calculated by Δ/S is related to the beta energy; i.e., the higher the energy, the greater the calculated mass. Apparently, however, the red marrow "S" factors for ^{3}H, ^{14}C, ^{32}P, ^{35}S, ^{45}C, ^{90}Sr, and ^{90}Y are based on a constant mass of 1,500 g and incorporate an absorbed fraction of 1.0, 0.94, 0.66, 0.94, 0.88, 0.75, and 0.65, respectively. Thus, the absorbed fraction is inversely related to the beta energy.