CALCULATING THE RADIATION DOSE TO AN ORGAN

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The Medical Internal Radiation Dose (MIRD) Committee of the Society of Nuclear Medicine has developed basic equations for calculating the radiation dose to a patient from a radiopharmaceutical. These equations are analyzed and modified so that the dose to a specific organ may be calculated when the radionuclide is not uniformly distributed in the body. Without the modifications, the dose to a target organ may be overestimated because the amount of radionuclide in the organ is included in the equation twice.

The dose to a patient from a radiopharmaceutical is usually calculated with the help of the equations published by the Society's Medical Internal Radiation Dose (MIRD) Committee (*1*). When calculating the dose to an organ irradiated by activity in that organ and in surrounding organs or the remainder of the body, care must be taken that the activity in the target organ is not used twice in the calculation. To avoid this problem, Smith (*2*) suggested a method which can be described by considering the dose to the spleen when irradiated by activity in the spleen and the total body.

$$\bar{D}_s = \frac{\tilde{A}_s}{m_s}\Sigma\Delta_{np}\phi_{np} + \frac{\tilde{A}_s}{m_s}\Sigma\Delta\phi_{(s\leftarrow s)} + \left[\frac{\tilde{A}_{TB} - \tilde{A}_s}{m_s}\right]\Sigma\Delta\phi_{(s\leftarrow TB)}. \quad (1)$$

The meaning of the various symbols is given in Table 1.

The first and second terms in Eq. 1 give the nonpenetrating and penetrating radiation dose to the spleen from activity located in the spleen. The last term is meant to provide the dose to the spleen from the remaining activity which is distributed throughout the body but outside the spleen.

It is now recognized that the third term fails to provide sufficient correction since the absorbed fraction, $\phi_{(s\leftarrow TB)}$, is based on the uniform distribution of the radionuclide in the total body including spleen (*3*). Because the absorbed fraction depends on the geometry of the system, its magnitude is greatly influenced by the activity in the spleen. What is required is an absorbed fraction for spleen from total body minus spleen, $\phi_{(s\leftarrow[TB-s])}$. This fraction is not available in the MIRD pamphlets (*3*). Using available absorbed fractions, the proper dose equation would be

$$\bar{D}_s = \frac{\tilde{A}_s}{m_s}\Sigma\Delta_{np}\phi_{np} + \frac{\tilde{A}_s^*}{m_s}\Sigma\Delta\phi_{(s\leftarrow s)} + \frac{\tilde{A}_{unif}}{m_s}\Sigma\Delta\phi_{(s\leftarrow TB)}, \quad (2)$$

where $\tilde{A}_s^*$ is the cumulated activity in the spleen in excess of or less than the activity uniformly distributed throughout the body, $\tilde{A}_{unif}$, and can be either a positive or a negative value. Thus,

$$\tilde{A}_s^* = \tilde{A}_{TB} - \tilde{A}_{unif}. \quad (3)$$

The total cumulated activity in the spleen is related to the excess or deficit spleen activity as

$$\tilde{A}_s = \tilde{A}_s^* + \frac{m_s}{m_{TB}}\tilde{A}_{unif}. \quad (4)$$

This equation assumes that the radionuclide is distributed uniformly according to the masses of the

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TABLE 1. EXPLANATION OF SYMBOLS

Symbol	Definition
$\bar{D}_t$	Mean dose to a target organ, e.g., $\bar{D}_s$ = mean dose to spleen (rads)
$\tilde{A}$	Cumulated activity (μCi-hr)
m	Mass (gm)
Δ	Equilibrium dose constant (gm-rad/μCi-hr)
np	Nonpenetrating radiation
φ	Absorbed fraction, e.g., ϕ_{np} = absorbed fraction for nonpenetrating radiation; $\phi_{(s\leftarrow s)}$ = absorbed fraction for penetrating radiation to spleen from spleen
TB	Total body

various organs (Fig. 1). Solving Eqs. 3 and 4 for $\tilde{A}_{unif}$ and $\tilde{A}_s{}^*$ gives

$$\tilde{A}_{unif} = \left[\frac{m_{TB}}{m_{TB} - m_s}\right][\tilde{A}_{TB} - \tilde{A}_s] \qquad (5)$$

and

$$\tilde{A}_s{}^* = \frac{m_{TB}\tilde{A}_s - m_s\tilde{A}_{TB}}{m_{TB} - m_s}. \qquad (6)$$

If Eq. 6 is multiplied by m_{TB}/m_{TB}, it may be factored to give

$$\tilde{A}_s{}^* = \left[\frac{m_{TB}}{m_{TB} - m_s}\right]\left[\tilde{A}_s - \frac{m_s}{m_{TB}}\tilde{A}_{TB}\right]. \qquad (7)$$

Substituting for $\tilde{A}_{unif}$ and $\tilde{A}_s{}^*$ into Eq. 2 gives

$$\bar{D}_s = \frac{\tilde{A}_s}{m_s}\Sigma\Delta_{np}\phi_{np} + \left[\frac{m_{TB}}{m_{TB} - m_s}\right]\left[\frac{\tilde{A}_s}{m_s} - \frac{\tilde{A}_{TB}}{m_{TB}}\right]\Sigma\Delta\phi_{(s\leftarrow s)} + \left[\frac{m_{TB}}{m_{TB} - m_s}\right]\left[\frac{\tilde{A}_{TB} - \tilde{A}_s}{m_s}\right]\Sigma\Delta\phi_{(s\leftarrow TB)}. \qquad (8)$$

The first term in Eq. 8 (exactly the same as in Eq. 1) gives the dose to the spleen from nonpenetrating radiation. The second and third terms together give the penetrating radiation dose to the spleen. The third term is that part of the dose that results from activity uniformly distributed throughout the body. The second term provides the dose from excess (or deficit) activity in the spleen.

Since $m_s << m_{TB}$,

$$\frac{m_{TB}}{m_{TB} - m_s} = \frac{70{,}000}{70{,}000 - 176} = 1.0025 \approx 1.$$

Therefore, Eq. 8 can be simplified to

$$\bar{D}_s = \frac{\tilde{A}_s}{m_s}\Sigma\Delta_{np}\phi_{np} + \left[\frac{\tilde{A}_s}{m_s} - \frac{\tilde{A}_{TB}}{m_{TB}}\right]\Sigma\Delta\phi_{(s\leftarrow s)} + \left[\frac{\tilde{A}_{TB} - \tilde{A}_s}{m_s}\right]\Sigma\Delta\phi_{(s\leftarrow TB)}. \qquad (9)$$

Because $m_{TB}/(m_{TB} - m_t)$ is very nearly equal to 1 for most body organs, Eq. 9 will usually be adequate for dose calculations.

When the activity in surrounding organs contributes greatly to the target organ's dose, the more general Eq. 10 should be used.

$$\bar{D}_t = \bar{D}_{np} + \sum_{k=a}^{t} \bar{D}_p{}^*_{(t\leftarrow k)} + \bar{D}_p{}^*_{(t\leftarrow TB)}, \qquad (10)$$

where $\bar{D}_{np}$ is the nonpenetrating radiation dose to the target organ from itself and is the same as in Eqs. 1, 2, 8, and 9. The second term, $\sum_{k=a}^{t} \bar{D}_p{}^*_{(t\leftarrow k)}$, provides the penetrating radiation dose to the target organ from "excess" activity in itself and the other body organs (k = a,b,c . . . t). Excess activity is defined as the activity in the source organ in excess or deficit of that uniformly distributed throughout the body (Fig. 2). The value of $\bar{D}_p{}^*_{(t\leftarrow k)}$ is

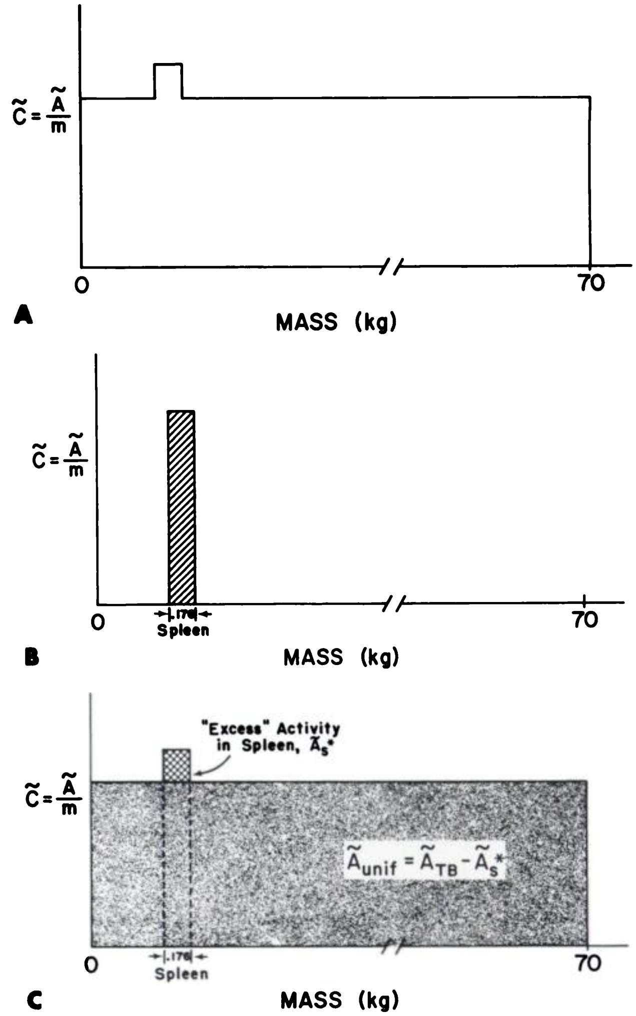

FIG. 1. Graphical concept of dose terms used when only target organ and total body are considered in calculating the dose: (A) cumulated activity in total body, $\tilde{A}_{TB} = \tilde{C} \times m_{TB}$; (B) cumulated activity in spleen; (C) "excess" activity in spleen and activity uniformly distributed in total body.

$$\bar{D}_p{}^*_{(t\leftarrow k)} = \frac{\tilde{A}_k{}^*}{m_t}\Sigma\Delta\phi_{(t\leftarrow k)} = \frac{1}{m_t}\left[\tilde{A}_k - \frac{m_k}{m_{rem}}\tilde{A}_{rem}\right]\Sigma\Delta\phi_{(t\leftarrow k)}, \qquad (11)$$

where

$$\tilde{A}_{rem} = \tilde{A}_{TB} - \sum_{k=a}^{t}\tilde{A}_k \text{ and } m_{rem} = m_{TB} - \sum_{k=a}^{t} m_k.$$

Inspection of Fig. 2 reveals that $\tilde{A}_{unif}/m_{TB} = \tilde{A}_{rem}/m_{rem}$ if one assumes that the remainder of the activity, $\tilde{A}_{rem}$, is distributed according to the ratio of m_k/m_{rem}. When more information on actual dis-

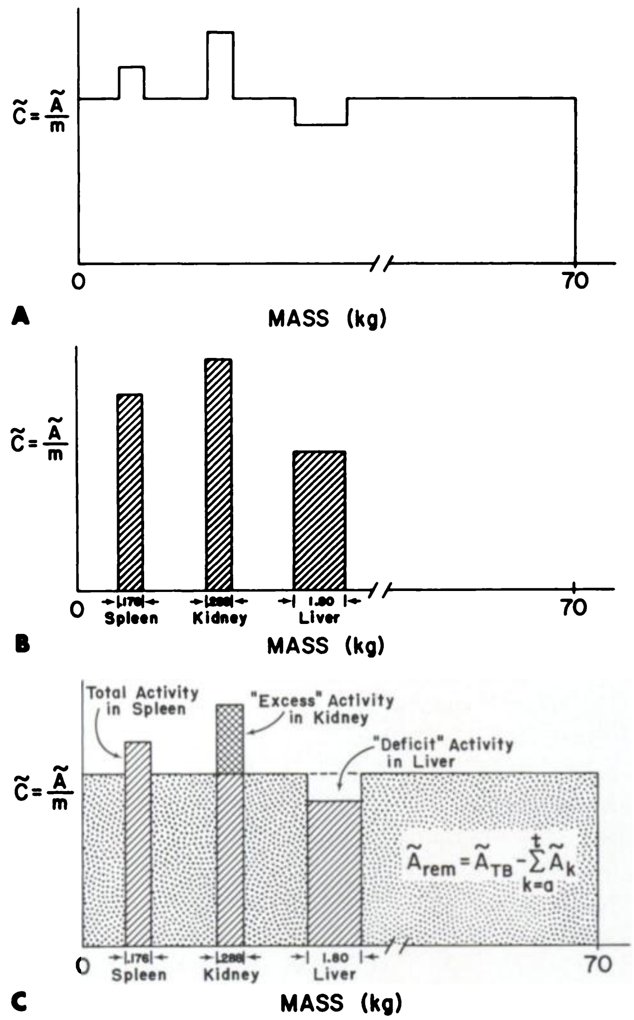

FIG. 2. Graphical concept of dose terms used when target organ, other source organs, and total body are considered in calculating the dose: (A) cumulated activity in total body; (B) cumulated activity in source organs; (C) total activity in spleen, "excess" activity in kidney, "deficit" activity in liver, remainder activity, $\tilde{A}_{rem}$.

tributions becomes available, it may be necessary to use a ratio of "spaces" or "pools."

The third term in Eq. 10, $\bar{D}_p{}^*{}_{(t\leftarrow TB)}$, gives the dose to the target organ from activity uniformly distributed throughout the body.

$$\bar{D}_p{}^*{}_{(t\leftarrow TB)} = \frac{\tilde{A}_{unif}}{m_t}\Sigma\Delta\phi_{(t\leftarrow TB)}$$

$$= \frac{m_{TB}}{m_t}\left[\frac{\tilde{A}_{rem}}{m_{rem}}\right]\Sigma\Delta\phi_{(t\leftarrow TB)}. \quad (12)$$

By substitution, Eq. 10 becomes

$$\bar{D}_t = \bar{D}_{np} + \sum_{k=a}^{t}\frac{1}{m_t}\left[\tilde{A}_k - \frac{m_k}{m_{rem}}\tilde{A}_{rem}\right]\Sigma\Delta\phi_{(t\leftarrow k)}$$

$$+ \frac{m_{TB}}{m_t}\left(\frac{\tilde{A}_{rem}}{m_{rem}}\right)\Sigma\Delta\phi_{(t\leftarrow TB)}. \quad (13)$$

This equation will reduce to Eq. 8 or its approximation, Eq. 9, when only the activity in one organ and in the total body is considered.

Blau (*4*) and Snyder (*5*) have pointed out that the absorbed fraction for $\phi_{(t\leftarrow rem)}$ can be obtained from published absorbed fractions by using the following relationship:

$$\phi_{(t\leftarrow rem)} = \frac{m_{TB}}{m_{rem}}\left\{\phi_{(t\leftarrow TB)} - \frac{m_t}{m_{TB}}\cdot\phi_{(t\leftarrow t)} - \frac{m_k}{m_{TB}}\cdot\phi_{(t\leftarrow k)}\right\},$$

where

$$\tilde{A}_{rem} = \tilde{A}_{TB} - \sum_{k=a}^{t}\tilde{A}_k \text{ and } m_{rem} = m_{TB} - \Sigma m_k.$$

Thus the general dose equation may also be written as

$$\bar{D}_t = \frac{\tilde{A}_t}{m_t}\Sigma\Delta_{np}\phi_{np} + \sum_{k=a}^{t}\frac{\tilde{A}_k}{m_t}\Sigma\Delta\phi_{(t\leftarrow k)}$$

$$+ \frac{\tilde{A}_{rem}}{m_t}\Sigma\Delta\phi_{(t\leftarrow rem)}. \quad (14)$$

Roedler, et al (*6*) recently arrived at an equivalent equation by using a slightly different logic path.

SUMMARY

These equations are merely refinements in the way the basic MIRD dose equations are to be used. The choice of which equation to use (8, 9, 13, or 14) will depend upon the form in which the raw data are available. The accuracy of the dose estimates will be no better than the biological and physical data used for the calculations.

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