ABSORBED DOSE CALCULATIONS FOR ^{113m}In PLACENTAL SCANNING

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Indium-113m-hydroxide (pH 3.4) has recently been introduced as a blood-pool scanning agent. When used to visualize the placenta, this radiopharmaceutical has distinct advantages over ^{99m}Tc-labeled serum albumin because of its low urinary excretion and ease of preparation.

Little information is available regarding the radiation dose to the mother and fetus resulting from the use of this agent.

In the present study the biological half-life of the ^{113m}In blood-pool scanning preparation was determined in pregnant females and the transfer across the placenta measured in the pregnant female South African baboon (*Papio ursinus*).

PREPARATION OF SCANNING AGENT

Indium-113m was eluted from a ^{113}Sn generator with dilute HCl (pH 1.3). To 8 ml of the eluate, 1 ml 5% NaCl solution was added and the pH adjusted to 3.4. After autoclaving, doses of 1 mCi were used intravenously in all the studies.

PHYSICAL HALF-LIFE

Indium-113m (Fig. 1) decays by a single isomeric transition which undergoes 35.5% internal conversion. Gamma photons of 0.3917 MeV are emitted in 64.5% of the decay processes (*1*).

The physical half-life was determined because different values, ranging from 1.65 to 1.73 hr, have been published.

Samples of the ^{113m}In eluant were evaporated to dryness in a counting vial and counted in an automatic gamma sample counter system. Counting was done for 2 min over a period of 360 min.

Regression analysis on deadtime-corrected counts was performed and the slope of the regression equation,

$$Y = 1.91415 - 0.69269X,$$

with a regression coefficient of $r = 0.999937$ resulted in a physical half-life of

$$T_{1/2} = 1.667 \text{ hr (Fig. 2)}.$$

LOCAL ENERGY DEPOSITION PER DISINTEGRATION

The local energy deposit per disintegration, $n_e\bar{E}_e$, due to internal-conversion electrons was calculated according to the method of Smith, Harris and Rohrer (*2*) and is given by

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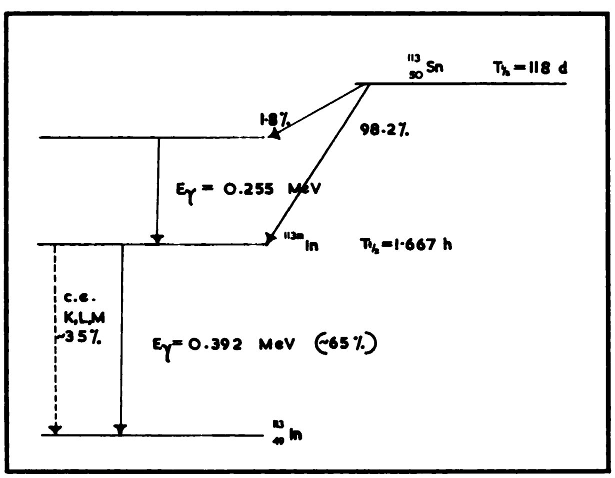

FIG. 1. Decay scheme of ^{113}Sn-^{113m}In.

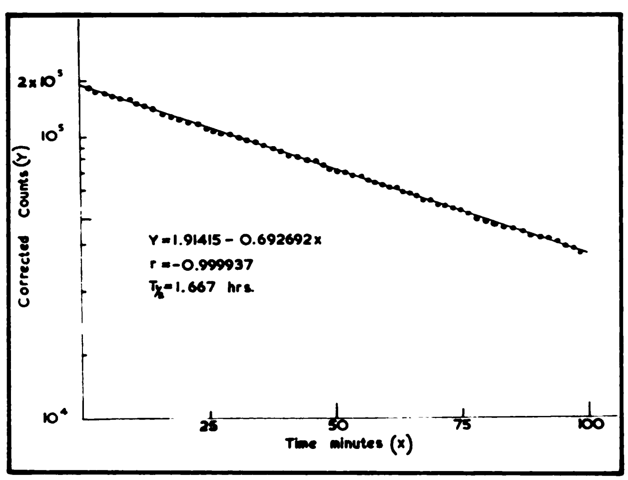

FIG. 2. Physical half-life of ^{113m}In.

TABLE 1. EQUILIBRIUM ABSORBED DOSE CONSTANTS: THE VARIOUS ENERGY COMPONENTS

Type of radiation	n_i (per dis)	$\bar{E}_i$ (MeV)	$n_i\bar{E}_i$ (MeV/dis)	Δ_i $\left(\frac{\text{gm-rad}}{\mu\text{Ci-hr}}\right)$	Γ_i $\left(\frac{\text{R-cm}^2}{\text{mCi-hr}}\right)$
Internal conversion electrons	—	—	0.13259	0.2825	—
γ	0.645	0.3917	0.25265	0.5384	1.43
K_α x-rays	0.20526	0.0241	0.00495	0.0105	0.270
K_β x-rays	0.041239	0.0273	0.00113	0.0024	0.043

$$\Gamma_t = 1.743 \frac{\text{R-cm}^2}{\text{mCi-hr}}$$

$$n_e\bar{E}_e = f_\gamma N_{eK} \left\{ E_\gamma - \omega_K E_K + \omega_K \left[\left(\frac{K_\alpha}{K_\alpha + K_\beta}\right) E_{L_{II\text{-}III}} + \left(\frac{K_\beta}{K_\alpha + K_\beta}\right) E_{M_{II\text{-}III}}\right]\right\} + f_\gamma E_\gamma (N_{eL} + N_{eM}) \text{ MeV/dis} \quad (1)$$

where f_γ = fractional frequency of the disintegrations that gives rise to a photon of energy E = 0.3917 MeV
= 1.00,
ω_K = K-fluorescent yield
= 0.850 (*3*),
E_K = bind energy of K-electrons
= 0.0279 Mev (*4*)
$E_{L_{II\text{-}III}}$ = average binding energies of L_{II} and L_{III} electron shells, where $E_{L_{II}} = 0.003929$ MeV and $E_{L_{III}} = 0.003732$ MeV (*4*),
$E_{M_{II\text{-}III}}$ = average binding energies of M_{II} and M_{III} electron shells where $E_{M_{II}} =$ 0.000691 and $E_{M_{III}} = 0.000653$ MeV (*4*),
$\frac{K_\alpha}{K_\alpha + K_\beta}$ = relative abundance of the K_α x-rays emitted per disintegration as the result of K internal conversion,
= 0.8327 (*5*),
$\frac{K_\beta}{K_\alpha + K_\beta}$ = relative abundance of the K_β x-rays emitted per disintegration as the result of K internal conversion,
= 0.1673 (*5*),
and $N_{et} = N_{eK} + N_{eL} + N_{eM}$,
= total number of conversion electrons.

The value of N_{et} can be calculated from the total internal-conversion coefficient $\alpha_t = 0.55$ (*6*) and the K internal conversion coefficient $\alpha_K = 0.45$ (*7*) where $N_{et} = \frac{\alpha_t}{1 + \alpha_t}$.

The numbers of K electrons and of L plus M electrons which undergo internal conversion, respectively, are

$$N_{eK} = \frac{\alpha_K}{1 + \alpha_t} = 0.29$$

and $N_{eL} + N_{eM} = 0.064$.

Substituting the above values into Eq. 1 gives

$$n_e\bar{E}_e = 0.13259 \text{ MeV/dis.}$$

GAMMA PHOTON YIELD

The number of unconverted photons is given by

$$n_\gamma = 0.645 \text{ photons/dis.}$$

CHARACTERISTIC X-RAY YIELD

The K_α and K_β x-ray yield is

$$n_{K\alpha} = 0.20526 \text{ photons/dis.}$$
$$n_{K\beta} = 0.041239 \text{ photons/dis.}$$

TOTAL ENERGY LIBERATED PER DISINTEGRATION

The equilibrium absorbed dose constant, Δ, is given by

$$\Delta = \Sigma \Delta_i = \sum_i n_i\bar{E}_i \text{ MeV/dis}$$
$$= 2.131 \sum_i n_i E_i \text{ gm-rad}/\mu\text{Ci-hr}$$

where n_i is the fractional frequency of ith type of radiation with energy E_i MeV. The values of Δ_i are listed in Table 1.

The specific gamma-ray constant, Γ, is not used in the calculation of the absorbed dose but is useful in shielding calculations or source calibrations. The specific gamma-ray constant (Table 1) is given by (*8*)

$$\Gamma = 1.5 \times 10^5 \sum_i n_i\bar{E}_i \, \mu_{air} \text{ cm}^2\text{-R/mCi-hr.}$$

INDIUM-113m BIOLOGICAL HALF-LIFE IN THE BLOOD

The biological half-life of ^{113m}In in blood for placenta scanning was determined in three pregnant women over a period of 5 hr. Blood samples were counted in a scintillation well counter and expressed as a percentage of the 5-min blood sample. The results were corrected for physical decay for the time between counting the standard and the samples.

Regression analysis was performed, and a biological half-life (for blood) of $T_b = 6.74$ hr with a regression coefficient of 0.97553 was found (Fig. 3).

The value of the half-life is similar to that obtained for ^{99m}Tc-labeled albumin and ^{131}I-labeled albumin, but differs from the approximately 3-hr value reported for ^{113m}In (*9*).

ABSORBED DOSE

The absorbed dose to the maternal total body and blood was calculated using an average total-body weight of 65 kg with a blood volume of 60 ml/kg. It was assumed that the activity was uniformly distributed in an ellipsoidal body (*10*).

Total-body absorbed dose. The physical decay of ^{113m}In was used to calculate the total-body absorbed dose because the amount of ^{113m}In found in the urine (Fig. 4) and feces over a period of 4 hr was only 0.1%.

The average total-body dose is given by (*11*)

$$\bar{D}_\infty (v \leftrightarrow v) = \tilde{C}_v \sum_i \Delta_i \phi_i (v \leftrightarrow v) \text{ rad}$$

where $\tilde{C}_v = 1.44 \sum_i C_i(0)\, T_{i\,eff}$ μCi-hr/gm,

$C_i(0)$ = initial concentration,

$T_{i\,eff}$ = effective half-life,

ϕ_i = absorbed fraction (*10–13*) of the ith type radiation.

The values of $\Delta_i\ \phi_i$ are given in Table 2 for a 65-kg ellipsoid.

The total-body dose $\bar{D}_\infty$ $(v \leftrightarrow v)$ per 1 mCi ^{113m}In administered for placental scanning and effective half-life of 1.667 hr is

$$\bar{D}_\infty (v \leftrightarrow v) = 0.0176 \text{ rad.}$$

Maternal blood absorbed dose. For the beta-type or nonpenetrating component of the absorbed dose to the blood, it is assumed that the activity is uniformly distributed in the blood. The biological disappearance of the ^{113m}In in the blood consists of only one component, resulting in an effective half-life of

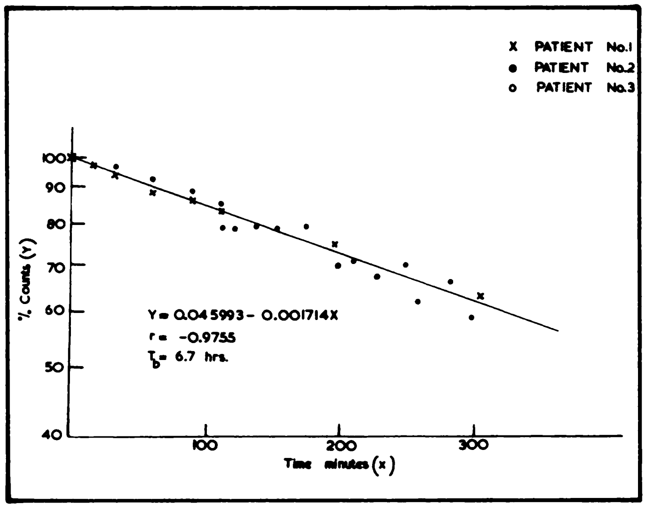

FIG. 3. Biological half-life of ^{113m}In scanning agent.

FIG. 4. Normal placental scan with ^{113m}In placental scanning agent. Activity in bladder region is insignificant.

TABLE 2. ABSORBED FRACTIONS FOR 65-KG ELLIPSOID WITH UNIFORM ACTIVITY AND CENTRAL POINT ACTIVITY DISTRIBUTED FOR VARIOUS ENERGY COMPONENTS

Type of radiation	$\bar{E}_i$ (MeV)	Δ_i (gm-rad/μCi-hr)	Uniform activity ϕ_i	Uniform activity $\phi_i\Delta_i$	Central point activity ϕ_i	Central point activity $\phi_i\Delta_i$
Internal-conversion electrons	—	0.2825	1.000	0.2825	1.000	0.2825
γ	0.3917	0.5384	0.340	0.1831	0.486	0.2617
Kα x-rays	0.0241	0.0105	0.840	0.0088	0.990	0.0104
Kβ x-rays	0.0273	0.0024	0.790	0.0019	0.980	0.0024
			$\sum_i \phi_i\Delta_i$	0.4763		0.5570

TABLE 3. COMPARISON OF ABSORBED DOSE FROM ^{99m}Tc-SERUM ALBUMIN FOR PLACENTAL SCANNING, ^{131}I-SERUM ALBUMIN FOR PLACENTAL LOCALIZATION, ^{113m}In FOR PLACENTAL SCANNING AND DIAGNOSTIC X-RAY PELVIMETRY

Radiopharmaceutical and dose (mCi)	Organ	Absorbed dose (mrad) Nonpenetrating	Penetrating	Total
^{99m}Tc-albumin (14)*	Maternal total body	4	13	17
1 mCi	Maternal blood	34	13	47
	Fetal blood	0.7	13	14
^{131}I-albumin (14)†	Maternal total body	5	0.2	5.0
0.005 mCi	Maternal blood	83	4	87
	Fetal blood	1	4	5
^{113m}In	Maternal total body	10	7	17
1 mCi	Maternal blood	139	7	146
	Fetal blood		8	8
General diagnostic radiology (pelvimetry) (15)	Mean gonadal dose/examination	Female		745mR
		Fetus		885mR

* Mother pretreated with potassium perchlorate.
† Mother pretreated with Lugol's solution.

$$T_{eff} = 1.377 \text{ hr}.$$

It is assumed that the beta-radiation component is completely absorbed in the blood to give a dose of

$$\bar{D}_{\infty\ n\text{-}p} = 0.139 \text{ rad}.$$

The contribution from the gamma component is equal to the gamma component of the total-body dose to give a total absorbed dose in blood of

$$\bar{D}_{\infty} = 0.146 \text{ rad}.$$

Fetal blood absorbed dose. It is assumed that the fetus is in the center of the ellipsoid and that it would receive the absorbed dose of the ellipsoid at the central axis (Table 2).

The contribution of the gamma component to the total dose absorbed by the fetus is

$$\bar{D}_{\infty\ \gamma} = 0.008 \text{ rad}.$$

Two pregnant baboons were injected with 1 mCi ^{113m}In placenta scanning agent to measure transfer of ^{113m}In across the placenta.

A cesarean section was performed 30 min after injection of ^{113m}In, and blood samples were taken from the fetus and the mother. The mean percentage activity in the fetal blood was less than 0.1% of that of the mother. The contribution of the nonpenetrating component of ^{113m}In in the fetus can thus be neglected to give a total fetal dose of

$$\bar{D}_{\infty} = 0.008 \text{ rad}.$$

SUMMARY

By using ^{113m}In as a scanning agent, the absorbed dose to the total maternal body and the maternal and fetal blood was calculated. A 65-kg maternal body weight with a blood volume of 60 ml/kg and a fetal body weight of 3.9 kg was assumed. The biological half-life of ^{113m}In in the blood was found to be 6.74 hr. In the first 4 hr after administration of ^{113m}In the activity in the urine was found to be less than 0.1%. Therefore the physical half-life was used in calculating the total-body absorbed dose.

The concentration of ^{113m}In in the fetal blood was less than 0.1% of the concentration in the maternal blood.

The absorbed dose received from 1 mCi ^{113m}In to the total maternal body is 17 mrad, maternal blood is 146 mrad (Table 3) and fetal blood is 8 mrad.

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