TECHNICAL NOTES

Radiation Dose Estimates for Oral Agents Used in Upper Gastrointestinal Disease

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Radiation dosimetry was calculated for a number of orally administered radiopharmaceuticals used for study of upper gastrointestinal function. These include: Tc-99m sulfur colloid in water, in a cooked egg, and in chicken liver labeled in vivo; In-111 DTPA; Tc-99m DTPA; In-113m DTPA; Tc-99m ovalbumin in cooked egg; and In-111 colloid in chicken liver labeled in vivo. Radiation burdens to the stomach, small intestine, upper and lower large intestine, ovaries, testes, and total body are calculated for each preparation.

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Within the past five years, a number of different radioagents and techniques have been introduced for the study of upper gastrointestinal function. The new diagnostic tests include esophageal transit studies, gastroesophageal scintigraphy, gastric emptying of mixed liquid and solid meals, bile reflux scintigraphy, and combined imaging procedures of the gallbladder and stomach (*1–6*). In the course of introducing oral application of intravenously administered radiopharmaceuticals, it was first necessary to perform tissue distribution studies in two animal species (one of which was not a rodent) in order to make preliminary estimates of radiation dose. Subsequent to certification by the institutional review committees, patient studies were performed and the biokinetics of the orally administered agents were observed in patients.

The purpose of this study is to report estimates of radiation burden for studies of upper gastrointestinal function using the following orally administered radiopharmaceuticals: technetium-99m sulfur colloid in water, In-111 DTPA in water, Tc-99m DTPA in water, In-113m DTPA in water, Tc-99m ovalbumin, Tc-99m sulfur colloid in a cooked egg, and chicken liver labeled in vivo with Tc-99m colloid or In-111 colloid.

MATERIALS AND METHODS

Radiopharmaceutical preparation. *A. Liquids. 1. Tc-99m Sulfur Colloid (SC).* Tc-99m SC injection is prepared at ~500 μCi/ml, diluted 1:5 with normal saline solution (0.9%), USP, to a concentration of ~100 μCi/ml. The Tc-99m SC is then diluted with tap water to the appropriate volume (15 ml–300 ml) for the particular study, e.g., 15 ml for esophageal transit, 300 ml for esophageal reflux, etc.

2. In-DTPA. Indium-111 or In-113m DTPA is prepared for oral administration from the product supplied for intrathecal injection. Two hundred fifty microcuries is diluted with 300 ml tap water for studies of gastric emptying of a liquid. The commercial product contains 1.0 mCi/ml on the date of calibration.

B. Solids. 1. Chicken liver tagged in vivo with tc-99m sulfur colloid (or In-111 colloid). A live chicken is injected in a wing vein with 1 mCi of Tc-99m SC (or 250 μCi In-111 colloid). After 30 min the chicken is slaughtered and the liver is removed, rinsed in saline solution, and cooked.

2. Tc-99m-ovalbumin. This is prepared by labeling purified ovalbumin with Tc-99m by an electrolytic method similar to that of Dworkin and Gutkowski (*7*). The labeled ovalbumin is mixed with a beaten fresh egg, then cooked.

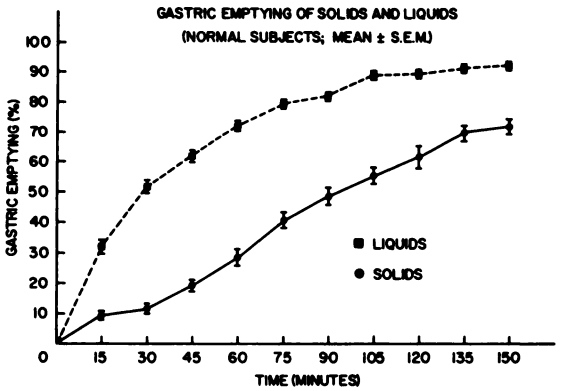

FIG. 1. Time-activity curves for gastric emptying of solid and liquid meals derived from 15 normal subjects.

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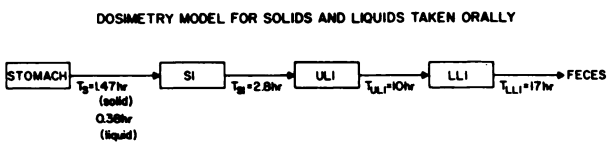

FIG. 2. Dosimetry model for oral agents.

TABLE 1. DOSIMETRY MODEL ASSUMPTIONS

1. At t = 0, the agent is taken orally.
2. There is no unlabeled activity.
3. The biological half-times of the preparations, as observed in 20 normal patient studies, are as follows:

Stomach	= 0.38 hr for liquid and 1.47 hr for solid;
Small intestine	= 2.8 hr;
Upper large Intestine	= 10 hr;
Lower large intestine	= 17 hr.

4. 100% of the ingested activity reaches the stomach instantaneously.
5. There is no renal clearance of the activity.

3. Tc-99m sulfur colloid egg: The Tc-99m SC is injected into a freshly beaten raw egg and the mixture cooked until firm in consistency.

METHODS

After oral administration of the appropriate radiopharmaceutical, the subject was positioned under the diverging collimator of a gamma camera. Ten normal subjects were studied for each radioagent. The camera was interfaced to a digital computer for subsequent data analysis. For all subjects, 1-min images were obtained over the stomach, with the subject supine, at 15-min intervals for 2 hr. The subjects were free to move about during the intervals between imaging.

RESULTS

The time-activity curves for the stomach are shown in Fig. 1 (*8*). The biological half-times in the stomach are 1.47 hr for solid food and 0.38 hr for liquid food, based on measurements in 20 normal patients. The clearance characteristics for the bowel were found to be consistent with the work of Eve (*9*). We therefore used Eve's data to determine the pharmacodynamics of the various agents in the bowel, except that we used an exponential excretion model whereas Eve used a bolus model. In order to normalize the two models, it was necessary to obtain the appropriate biological half-time t_b, by setting the cumulated activity integral,

$$\int e^{-0.693\ t/t_b} dt,$$

equal to the corresponding transit time reported by Eve.

These results are summarized in Fig. 2. The necessary assumptions are listed in Table 1.

The cumulated activities in the various source organs were calculated using the uptake and clearance parameters summarized in Fig. 2. The cumulated activities were calculated analytically following the method of Bernard and Hayes (*10*).

TABLE 2. RADIATION BURDEN FOR GASTROINTESTINAL SCINTIGRAPHIC STUDIES

	Organ absorbed dose (mrad)							
	Stomach	SI	ULI	LLI	GB	Ovaries	Testes	Total body
I. Esophageal motility or esophageal reflux 300 μCi Tc-99m sulfur colloid	28	83	160	97	—	29	2	5
II. Hepatocystic (with gallbladder stimulation at 1 hr)								
A. 5 mCi Tc-99m PIPIDA	120	880	1600	1000	1700	330	29	82
B. 5 mCi Tc-99m HIDA	120	1100	2000	1300	630	390	26	82
III. Gastric emptying								
A. 250 μCi In-111 DTPA	110	490	1100	2000	—	420	27	60
B. 1 mCi Tc-99m DTPA	93	280	520	320	—	98	5	20
C. 500 μCi In-113m DTPA	170	280	270	68	—	20	1	10
D. 500 μCi Tc-99m ovalbumin (or Tc-SC egg)	120	120	230	140	—	42	2	9
E. 250 μCi In-111 chicken liver	240	480	1100	1900	—	400	28	58
F. 500 μCi Tc-99m chicken liver	120	120	230	140	—	42	2	9
Combination studies								
1. Esophageal-gastroesophageal scintigraphy (comb.)	56	170	310	180	—	58	4	10
2. Gastro-hepatic (max) II + IIIA, or II + IIIC	290	1600	3100	3300	1700	810	56	140
3. Dual gastric IIIA + IIID or IIIF	230	610	1300	2200	—	460	29	69
IIIB + IIIE	340	760	1600	2300	—	500	33	78

For dosimetry purposes, no distinction is made between solid and liquid food after their passage through the stomach.

The dose to the target organs per unit administered activity can be expressed as (*11*):

$$\bar{D}_{k \leftarrow h} = S_{k \leftarrow h} \tilde{A}_h,$$

where $\bar{D}_{k \leftarrow h}$ denotes the mean absorbed dose (mrad) to target organ k, due to source organ h; $S_{k \leftarrow h}$ is the S-factor for organ h to organ k (mrad per mCi-hr); and $\tilde{A}_h$ is the cumulated activity in organ h (mCi-hr).

The mean total dose to target organ k ($\bar{D}_k$) is given as:

$$\bar{D}_k = \sum_h \bar{D}_{k \leftarrow h}$$

The dosimetry data are shown in Table 2. For completeness we have included our previously reported dosimetry estimates for Tc-99m HIDA and Tc-99m PIPIDA. The table summarizes the dosimetry for all current gastrointestinal scintigraphic procedures and shows the recommended administered dose for each preparation.

CONCLUSIONS

Orally administered radiopharmaceuticals for upper gastrointestinal studies afford the clinician and investigator valuable clinical and physiologic information not previously obtainable by other techniques. The radiation burden to the patient from single or sequential studies is acceptable in comparison to fluoroscopy, which results in approximately 5000 millirem per min of exposure. The variety of preparations listed above should make these types of studies available in any routinely equipped nuclear medicine laboratory.

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