DOES THE GI TRACT MODEL OF THE ICRP PROVIDE RELIABLE DOSE ESTIMATES ?

P. Roth, Ch. Hansen, E. Werner

Ges. f. Strahlen- und Umweltforschung, Inst. f. Biophysikal. Strahlenforschung, 6000 Frankfurt am Main, F.R.GERMANY

INTRODUCTION

For many essential and non-essential elements are the details of the intestinal absorptive pathways still poorly understood. There is increasing evidence that the walls of the small intestine are a more selective tissue than previously thought. As an example, Figure 1 illustrates the phenomenon of a transient intestinal retention component for ingested iron in man. After oral administration, there is a continuing excretion of iron for several weeks, far longer than the gastrointestinal transit time (as evidenced by the whole body retention of ^{51}Cr, which was administered simultaneously as a non-absorbable marker), and also far beyond the lifespan of the enterocytes. This fraction of the ingested iron can not have been transferred to the blood before, since after intravenous administration there is only a marginal excretion during that period (Fig.1). Since this transient iron retention in the gut walls depends on the body iron status and on pathophysiological conditions (1,2), it appears to reflect a hitherto unknown physiological mechanism which regulates iron absorption. Similar fine structures in the absorptive pathways are likely to exist also for other essential and non-essential elements.

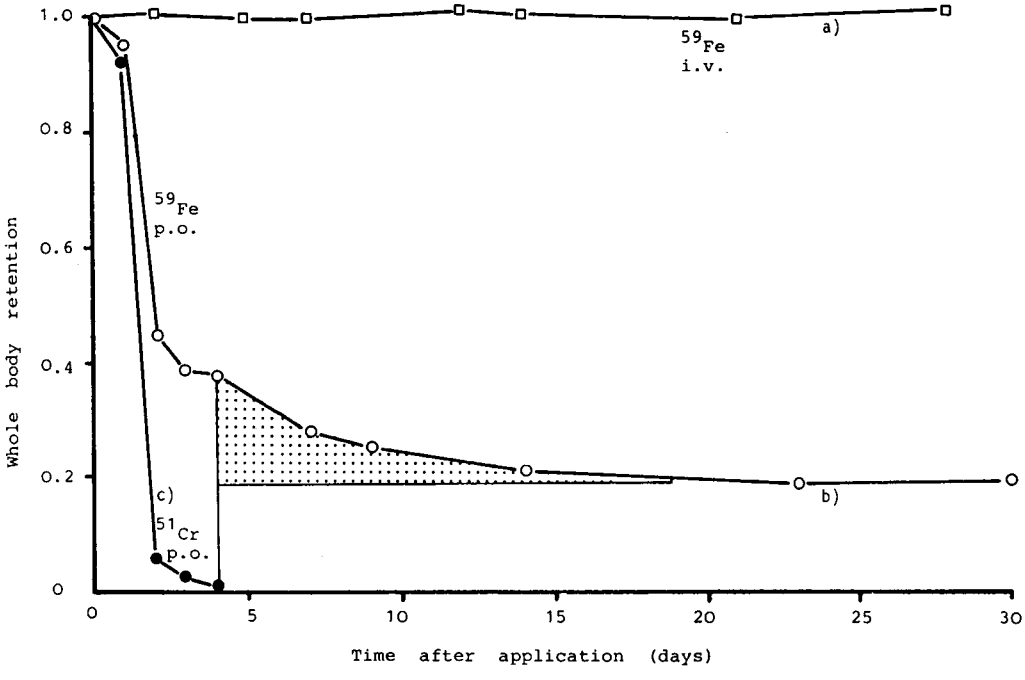

FIGURE 1. Whole body retention of intravenously administered ^{59}Fe (a), orally administered ^{59}Fe (b), and orally administered ^{51}Cr (c) in a healthy male subject.

These findings suggest that the current ICRP model for the gastrointestinal tract (3) might considerably underestimate radiation doses to the intestine, since this model does not account for any details in the absorptive processes. In the present study we therefore used the example of intestinal radioiron absorption in humans to evaluate the dosimetric consequences of a modified GI tract model.

RETENTION OF IRON IN THE GI TRACT

Absorption studies were performed in 23 healthy subjects with normal body iron status. The protocol of the absorption test is outlined in Table 1.

Figure 2 shows our suggested modification of the dosimetric model for the gastrointestinal tract. Instead of a direct transfer of activity from the small intestine to the systemic circulation, as in the ICRP model, the revised version takes account of retention of activity in the walls of the gut. According to this model, the whole body retention of the orally administered radioiron can be described by the following equation:

TABLE 1. Protocol of the radioiron absorption test.

23 healthy subjects with normal body iron status
Test dose: 100 ml deionized water 20 kBq ^{59}Fe-citrate 500 mg ascorbic acid 1mg / 5mg / 10mg / 20mg Fe^{2+} (ferrous sulphate) 0.4 MBq ^{51}Cr (Na_2CrO_4) (non-absorbable marker)
Whole body retention measurements of ^{51}Cr and ^{59}Fe for 3 - 15 weeks.

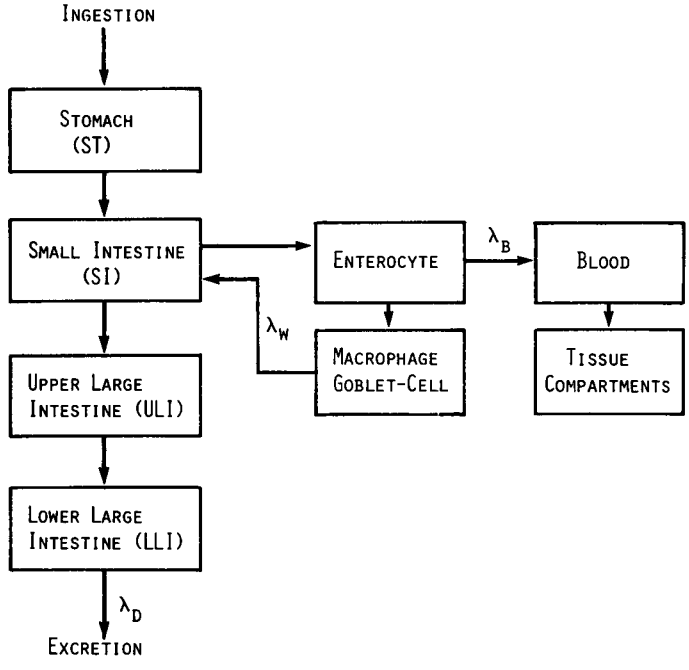

FIGURE 2. Modified dosimetric model for the gastrointestinal tract.

$$R_{WB} = f_1 + f_2 \cdot R_W(t) + (1-f_1-f_2) \cdot R_L(t) + f_2 \cdot \int_o^t R_W(t') \cdot R_L(t-t') \cdot dt'$$

with f_1 : fraction of administered activity transferred to the blood and tissue compartments,

f_2 : fraction of administered activity taken up by the gut walls but not transferred to the circulation,

$R_W(t)$: retention function of f_2; $R_W(t) = f_2 \cdot \exp(-\lambda_W \cdot t)$,

$R_L(t)$: retention of non-absorbed activity (gastro-intestinal passage).

Table 2 shows the values obtained for the absorbed fraction (f_1) and the submucosal retention component (f_2, λ_W). In normal subjects, about 1/3 of the radioiron taken up initially by the absorptive cells is finally transferred to the blood and tissue compartments, whereas 2/3 are temporarily retained in the gut walls and re-excreted into the lumen during the following weeks.

TABLE 2. Absorbed fraction (f_1) and temporarily retained activity component (f_2, λ_W) of orally administered radioiron in healthy subjects (mean values ± SD).

	ICRP - Model	Modified GI-Tract Model
f_1	0.1	0.20 ± 0.09
f_2	-	0.41 ± 0.24
$\lambda_W(d^{-1})$	-	0.24 ± 0.18

(n = 23)

DOSE CALCULATIONS

The calculations of absorbed doses were based on the MIRD concept (4) and were performed according to ICRP Publication 30, with the modifications of the GI tract model as described above.

The doses to the inner organs differ between the two models only with regard to the individual f_1-values (ICRP: f_1 = 0.1). According to the modified GI tract model, the dose to the gut wall has three sources: 1. from activity transferred to the blood and tissues; 2. from the activity retained in the gut walls (and re-excreted into the intestinal lumen); 3. from the activity in the lumen (non-absorbed and re-excreted). It was assumed that 2/3 of the absorption occurs in the duodenum and 1/3 in the jejunum. Iron, temporarily retained in the gut walls was thought to be uniformly distributed in half of the organ masses (duodenum: 30 g; jejunum: 140 g (males), and 125 g (females)). This was based on the assumption that the iron is retained in the gut wall but not in the muscles of the gut.

Table 3 compares the doses to the gut from orally administered ^{55}Fe and ^{59}Fe as calculated according to the two GI tract models. The doses to the gut walls from activity in the lumen and in the blood and tissues ($D_{B+L \rightarrow W}$) are very similar for both models. The additional dose component to the gut wall ($D_{W \rightarrow W}$), which is not considered in the ICRP model, however,

changes the total doses significantly. For ^{59}Fe as well as for ^{55}Fe, the doses to the duodenum increase by a factor of about 20, and to the jejunum by a factor of 3, as compared to the ICRP values.

TABLE 3. Radiation doses to the gut after oral administration of ^{59}Fe and ^{55}Fe. Comparison of ICRP data and values calculated according to the modified GI tract model.

Radio-nuclide	Dosimetric model	$D_{B+L \rightarrow W}$ (nSv/Bq)			$D_{W \rightarrow W}$ (nSv/Bq)	
		SI	ULI	LLI	Duodenum	Jejunum
^{59}Fe	ICRP 30	2.1	3.9	8.4	—	—
	Modified ICRP model	2.6 (+0.6)	4.3 (±0.9)	8.4 (±2.0)	38.5 (±24.4)	4.2 (2.6)
^{55}Fe	ICRP 30	0.12	0.17	0.30	—	—
	Modified ICRP model	0.21 (±0.09)	0.26 (±0.08)	0.37 (±0.08)	1.82 (±1.10)	0.19 (±0.12)

$D_{B+L \rightarrow W}$: Radiation dose to the gut wall from activity in blood and lumen,

$D_{W \rightarrow W}$: Radiation dose to the gut wall from activity retained in the gut wall (and re-excreted later).

CONCLUSIONS

Although radioiron is of limited interest in the field of radiation protection, it serves as a good illustration that the absorptive pathways of radionuclides deserve further investigations, especially in humans. Furthermore, any particular element should be considered in its own peculiarities and dosimetric models used should be based on a more physiological foundation, whenever such information is available.

REFERENCES

(1) Werner E, Kaltwasser JP, Bechstein PB: Untersuchungen zur Regulation des Eisenhaushalts. Nuklearmedizin und Biokybernetik. Berlin, Medico Informationsdienste (1978).

(2) Björn-Rasmussen E, Carneskog J, Cederblad A: Losses of ingested iron temporarily retained in the gastrointestinal tract. Scand. J. Haematol. 25, 124-126 (1980).

(3) The International Commission on Radiological Protection (ICRP). Limits for Intake of Radionuclides by Workers. ICRP Publication 30, Annals of the ICRP 5, Oxford, New York, Frankfurt, Pergamon Press (1981).

(4) Loevinger R, Berman M: A revised schema for calculating the absorbed dose from biologically distibuted radionuclides. MIRD Pamphlet No. 1, revised. New York, Society of Nuclear Medicine (1976).