Influence of Dietary Potassium, Rubidium, or Sodium on the Retention Time of Radiocesium in Rats* (32822)

JAMES E. JOHNSON, DAPHNE GARNER, AND GERALD M. WARD
(Introduced by R. E. Moreng)
Department of Animal Science, Colorado State University, Fort Collins, Colorado 80521

The fission product ^{137}Cs is a potential hazard to man and because of its metabolic similarity to potassium, the effect of dietary potassium and other alkali metals on cesium retention is of interest.

Mraz and Patrick (1) found that an increase of potassium in diet of rats increased the excretion rates of ^{134}Cs, ^{42}K, and ^{86}Rb, presumably because of the metabolic similarity of the three cations. Relman *et al.* (2) found that chronic feeding of equivalent amounts of rubidium and potassium or cesium and potassium to young rats allowed replacement of half or more of the muscle potassium by rubidium or cesium. They also suggested that the muscle cell accumulated the alkali metals in the order cesium > rubidium > potassium. Richmond and Furchner (3) found a very long retention time for ^{137}Cs in K deficient rats and also found that increasing K from 1% to 5% of the diet decreased retention twofold. Wasserman *et al.* (4) found that either Na or K fed to rats as 5% of the diet decreased body retention of ^{137}Cs which they interpreted as due to increased urinary loss associated with greater water consumption. Rama Sastry and Bush (5) found that the diuretic acetazolamide increased urinary ^{137}Cs excretion by a factor of 2 or 3 in the rat. They studied retention, however, only for short periods and the observed effect was probably on the short retention component.

Our interest in this problem was stimulated by the possible association between the relatively short half-retention time of ^{137}Cs in the cow and the usual consumption of high levels of potassium by dairy cattle. This study reports effects of K, Rb, and Na on ^{134}Cs retention by rats.

Materials and Methods. In the first experiment, twenty, 27-day-old, male rats (av wt. 60 gm) received a semi-purified diet containing 17.8% casein, 10.7% corn oil and 0.14% of a mix which supplied the required levels of vitamins and minerals (6) except for potassium. The remainder of the diet except for the added minerals consisted of corn starch. Rats were divided into 5 groups of 5 rats each which received diets of the following composition: group A, 0; B, 0.27; C, 0.89; D, 1.61; and E, 4.46% K by weight of the diet and as the chloride salt.

The Na experiment was conducted with the above basal diet to which was added for group A, 0% Na; group B received 1.6% K and 0.3% Na, and group C, 1.6% K and 2% Na. Four female rats which were 62 days old and averaged 195 gm at the start of the experiment were used in each group.

In the first Rb experiment 16 adults, 98 days old (av/wt. 270 gm) were distributed into 4 groups and were fed the same basal diet as above. Rubidium was added as the chloride salt for groups A, B, C, and D at the level of 0.1, 1.0, 1.8, and 4.0%, respectively. Groups C and D were later combined. In the second rubidium experiment 18 young rats were distributed into 6 groups (A–F) which received 0, 0.025, 0.05, 0.075, 0.1, or 0.2% Rb, respectively.

Each diet was analyzed for potassium, sodium, or rubidium by atomic absorption spectrometry as a check for accuracy in diet preparation. Rats were weighed weekly prior to the morning feeding. Room temperature was kept constant. All rats were injected subcutaneously with approximately 0.1 μC of high specific activity $^{134}CsCl$ on the fifth day after starting on the diet. Whole-body retention of the radionuclide was determined by placing the rats in a lucite holder which was set on top of 4-inch thick, 8-inch diameter NaI(*Tl*) scintillation crystal. The detector was shielded from background radiation and counting time was 2 min. The ^{134}Cs retention was estimated from the area under the 0.795 MeV absorption

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TABLE I. Effect of Dietary Potassium on the ^{134}Cs Half-Retention Time in the Infant Rat.

Diet	K (%)[a]	Feed intake[b] (gm/day)	K intake (mg/day)	$T_{1/2}$ (long component)[b] (days)
A	0.0	5.0	0	125.0
B	0.27	6.5	17.6	13.3
C	0.89	6.1	54.0	9.4
D	1.61	5.5	88.7	8.2
E	4.46	6.8	303.0	6.0

[a] As determined by atomic absorption spectrometry.

[b] Mean value for group of 5 rats/diet.

peak in the gamma-ray spectrum. Each animal was counted immediately after injection and then daily throughout each trial. Each trial continued for at least 20 days.

Results. The retention functions of ^{134}Cs for all rats were observed to be a sum of two exponential components. The intercept of the long component was greater than 90% of the total retention and the half-time of this component ($T_{1/2}$) was taken as the measure of muscle turnover of ^{134}Cs. The short component $T_{1/2}$ = 1–2 days) almost certainly represents turnover of the extracellular compartment.

Richmond and Furchner (3) used a computer curve-fitting technique to resolve retention functions into 3 components of about 1, 7, and 14 days for rats fed a diet 1.0% K (1%). In our experiment the 1% K diet resulted in a $T_{1/2}$ of 9.4 days for the long component.

The results of the K experiment are listed in Table I and the data is also plotted in Fig. 1. The K deficient diet resulted in noticeably poorer weight gains (Table II) and a biological half-retention time for ^{134}Cs of about 125

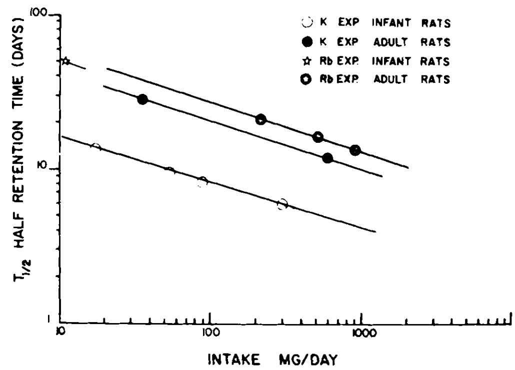

FIG. 1. The half-retention time of ^{137}Cs in infant and adult rats as a function of the intake of K or Rb.

days. As the K percentage in the diet increased, the weight gains were more normal and the ^{134}Cs $T_{1/2}$ decreased. The decrease in $T_{1/2}$, however, was not a linear function of the K dietary increase. Over the range of dietary levels used (excluding the K-deficient diet) the decrease was a factor of 2 for a tenfold increase in K intake. For this reason the data in Table I are plotted on log–log coordinates. The power function expression for the K curve is:

$$T_{1/2} = 31.6^{-2.91},$$

where I = K intake in mg/day.

Although log–log plots are commonly used to reduce variability of data, in this instance it was concluded that for a given increase in percentage of dietary K intake there was a constant decrease in $T_{1/2}$. Of more importance the $T_{1/2}$ can be predicted from the K intake. The effect of K on the ^{134}Cs $T_{1/2}$ is of the magnitude found by Richmond and Furchner (3) and by Wasserman *et al.* (4).

In the trial with Na the average consumption by the two supplemented groups

TABLE II. Weight Gains per Rat for Each Experimental Period.

Supplement to basal diet	Days on expt.	Mean wt. gain for experimental period (gm) Group A	B	C	D	E	F
Potassium	27	17.5	46.5	31.0	24.0	35.5	
Sodium + 1.6% K	20	18.0	16.9	22.5			
Rubidium (Expt. 1)	42	36.0	−16.0	−32.9			
Rubidium (Expt. 2)	35	6	16	28	33	25	34

TABLE III. The Effect of Dietary Rubidium Added to a Potassium Free Diet on the ^{131}Cs Half-Retention Time in the Adult Rat.

Diet	Rb (%)	Feed intake (gm/day)	Rb intake (mg/day)	$T_{1/2}$ (long component) (days)
A	0.089	8.2	7.3	20.5
B	0.80	6.6	53.2	16.1
C	1.61	5.6	90.8	13

was 28 mg of Na 165 mg of K/day and 186 mg of Na and 168 mg of K. The respective half-retention times were 14 and 12.7 days as compared to the previous experiment where 1.6% K produced a mean value of 8.2 days. Thus there was essentially no decrease in retention associated with a 6-fold increase in Na added to a high K diet. This is probably evidence against retention being primarily a function of diuresis or urine volume, although urine output was not measured in our trials. The results of Wasserman *et al.* (4) with 5% Na added to a diet containing 0.7% of K cannot be compared directly with our results.

In the first trial with Rb, the rats refused to eat a diet containing 4% Rb and this level was reduced to 1.6% (Table III). All of the rats in Groups B and C Rb died before the completion of the experiment. Death was preceded by severe weight losses as indicated in Table II. The toxicity of the Rb levels fed is apparent since growth occurred only on the K deficient diet containing 0.1% Rb. Interpretations of Rb effects on radiocesium retention were clouded by the toxic effects of the diet.

The rats used in this experiment were of adult weight and it is interesting that the data for all three groups followed a power function relationship. The slope of the line on log–log coordinates was observed to be nearly identical to the slope observed for the K experiment (Fig. 1).

Because of the apparent toxicity of Rb the second Rb experiment involved much lower concentrations of Rb (Table IV). However, only at the 0.2% level was there evidence of a decrease in the retention time of ^{134}Cs beyond that expected with a K deficient diet. The $T_{1/2}$ of 48 days for the 0.2% level of Rb is far greater than the value of 13 days found in the first experiment with a diet containing a similar level of K (0.27%).

The influence of age or weight has been shown to be a factor in radiocesium retention (7) and rats of different ages are included in this study. Two rats fed a high K diet (5%) for over 6 months and weighing 420 gm and two controls of similar weight and fed 0.3% K were also injected with ^{134}Cs. The half-retention time for the 5% K diet was 11 days and for 0.3% K diet was 29 days. The observed half-retention times for these groups are also plotted in Fig. 1, and again the slope is nearly identical to that for the K experiment with infant rats. A greater effect of weight or age on ^{134}Cs $T_{1/2}$ was observed in the K experiments than in the Rb experiments.

Discussion. In previous experiments of this type the alkali metals have been added to the diet and compared with each other on the basis of their weight in the diet. However, a given percentage of Na has nearly twice the activity of K (23 vs 39) and Rb only one half the activity of K. Thus, if cesium retention is influenced only by the ionic concentration in extracellular fluid, Na should be 4 times as effective as Rb on a weight percent basis. On the other hand, if the competition of alkali metals for intracellular sites controls cesium retention, then the data of Relman *et al.* (2) indicates that Rb should have 3 times the effect of K; while Na, primarily and extracellular ion, should have little influence on Cs retention according to this postulate.

The data indicates that Rb was less effective than K in decreasing the $T_{1/2}$ of ^{134}Cs. This may mean that the effect of Rb is a function of its chemical activity which is about one

TABLE IV. The Effect of Dietary Rubidium Added to a Potassium Free Diet on the ^{134}Cs Half-Retention Time in the Infant Rat.

Diet	Rb (%)	Feed intake (gm/day)	Rb intake (mg/day)	$T_{1/2}$ (long component) (days)
A	0	5.0	0	92
B	0.025	4.7	1.2	113
C	0.05	3.5	1.7	165
D	0.075	5.6	4.1	122
E	0.1	4.2	4.2	92
F	0.2	5.2	10.4	48

half of K on a weight basis. It obviously was not 3 times as effectve as postulated above. On an atoms percent basis K was, to the contrary, about 3 times as effective as Rb in the adults and 6 times as effective in the experiments with infant rats. Also since K is essential to growth it would be proportionately more effective than Rb in the growing animal as compared to the adult.

Summary. Increasing the K intake of rats above requirements reduced the half-retention time for ^{134}Cs but at a decreasing rate. Maximum intake was 5% which resulted in $T_{1/2}$ of 6 days. The Na added at 0.3 or 2% to high K diet had no influence on the $T_{1/2}$ for ^{134}Cs. The influence of Rb salts on ^{134}Cs retention would indicate that this ion is less effective than K. The decreased effect of Rb may be due to its failure to adequately substitute for K in normal muscle cell metabolism.

1. Mraz, F. R. and Patrick, H., Proc. Soc. Exptl. Biol. Med. 96, 497 (1957).

2. Relman, A. S., Lambie, Anne T., Burrows, S. A., and Roy, Arlene M., J. Clin. Invest. 36, 1249 (1951).

3. Richmond, C. R. and Furchner, J. E., Proc. Soc. Exptl. Biol. Med. 108, 797 (1961).

4. Wasserman, R. H., Comar, C. L., and Tapper, D. N., Proc. Soc. Exptl. Biol. Med. 113, 305 (1963).

5. Rama Sastry, B. V. and Bush, M. T., Science 136, 257 (1962).

6. National Research Council, Publ. 990, Nutrient requirements of Laboratory Animals, 1962.

7. Richmond, C. R., Furchner, J. E., and Trafton, G. A., Health Physics 7, 219 (1962).

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Transplantation in the Marmoset (*Callithricidae*): A Technique for Orthotopic, Fitted Skin Grafts* (32823)

R. P. PORTER[1] AND N. GENGOZIAN

Medical Division, Oak Ridge Institute of Nuclear Studies[2]

The marmosets, among the smallest of the New World (Platyrrhin) primates, have in their reproductive physiology three features that make them unique among mammals: (a) a greater than 80% frequency of twinning occurs (1,2); (b) the twinning is considered to be almost always dizygotic (2); and (c) a consistent placental vascular anastomosis occurs between the fetal twins (2,3). A natural, apparently inclusive, hematopoietic chimerism resulting from the biologic interaction of these three reproductive qualities has been demonstrated by Benirschke *et al.* (4) and Gengozian *et al.* (5). To the transplantation immunologist, therefore, the marmoset offers a unique biologic tool for the study of cellular immunologic tolerance. Thus, natural chimerism, occurring early in embryologic development, suggests that a state of immunologic tolerance must exist between the two genetically determined, different blood-forming systems of such twins. Studies on rare dizygotic humans and in more numerous cattle twins having natural chimerism have shown an almost indefinite allograft tolerance (6,7). To test tolerance to skin allografts between marmoset twins, it was necessary to develop a reproducible autograft technique. This paper sets forth procedures that permit successful skin grafting in the marmoset.

Materials and Methods. Animals. One of the three species of white-lipped tamarins, *Saguinus fuscicollis ssp.*[3] Hershkovitz (8), members of the marmoset family *Callithricidae* was used in this study. These tamarins, with

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[2] An operating unit of Oak Ridge Associated Universities, Inc., Oak Ridge, Tennessee, under contract with the United States Atomic Energy Commission.

[3] Designated as *Tamarinus nigricollis* in our previous publications.