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A STUDY OF THE IRRADIATION SYNDROME

Part I. Water, Electrolyte and Nitrogen Balances

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A STUDY OF THE IRRADIATION SYNDROME

Part I. Water, Electrolyte, and Nitrogen Balances

This investigation is concerned with water, electrolyte, and nitrogen balances in the irradiation syndrome, the relationship of these balances to each other, and their relation to water and electrolyte content of the various tissues of the body. The problem is complicated by the fact that many of the characteristic symptoms of irradiation sickness such as anorexia, fever, vomiting, diarrhea, infection, and possibly mineral-steroid alterations (1-5), are in themselves conducive to water, electrolyte and nitrogen abnormalities.

Resume of Previous Work

Water and ionic alterations in the irradiation syndrome have been studied by many workers, but the results obtained have been variable, due to different species of animals studied and the diversity of methods employed. Particularly in human subjects have dissimilar observations been noted, probably because relatively few persons studied have had total body irradiation or uniform amounts of irradiation, and because the depleted condition of many of these patients has tended to confuse the picture.

Blood potassium, sodium, and chloride have been reported as normal or as showing inconsistent changes in dogs (6-9) and rats (10). Cameron and McMillan (11) found decreased plasma chloride inconstantly in humans. Pohle (7) cited three authors who described in humans transient lowering of chloride immediately after irradiation, with a rise to normal shortly thereafter. Pohle could not confirm this observation in dogs. Kohn (12a, b) observed rises and falls of chloride, sometimes phasic in character, in guinea pigs and in rats.

In Moon's (13) series of dogs subjected to large doses of x-irradiation, there was a rise in blood potassium associated with a shock-like state.

Bennett, Bennett and Howland (14) found a rise in serum radiosodium in rats, and a concomitant fall in urinary sodium. Painter (15) noted an increase in sodium space. Excretions of potassium, sodium and chloride were increased in rats during postirradiation days 1 to 4, according to Edelman (16). Bowers and Scott (10), using radiopotassium and radiosodium, also in rats, found increased excretions of potassium in the urine, reciprocal decrease in urinary sodium, and increased potassium and sodium in diarrheal stools. Two authors (11, 17) have reported sodium chloride retention in x-irradiated humans. On the other hand, Goldman (18) found a negative chloride balance, as did Ellinger (19) who incriminated the adrenal. An ionic balance study (in scope similar to ours) was done by Philips et al (20) following large doses of nitrogen mustard in dogs.

There is a paucity of nitrogen excretion data in the literature. Hall and Whipple (21) noted increased excretion on non-protein nitrogen after abdominal irradiation in dogs. Prosser et al (22) measured nitrogen balance in eight dogs which received 200-400 r. These authors found nitrogen balance to be normal until a "late depression period" was reached, when a negative balance occurred greater than that observed in control animals starved to the same extent. Negative nitrogen balances have been noted in patients undergoing x-ray therapy (18).

It has been stated (Prosser, 22) that loss of water through respiration probably is reduced after irradiation. Polydipsia and polyuria have been variously reported in both rats and dogs. France (23) observed increased plasma volume, thiocyanate space, muscle water, and total body water in rats and mice following moderate dosage of x-rays. Soberman et al (6) found no consistent changes in the water space of dogs except for increased plasma volume. Various investigators (6, 22, 23, 24) have commented on the relatively small change in blood volume despite the development of anemia; this was attributed to increase in plasma volume.

It will be noted in the sections which follow that some of the observations cited above have been confirmed by us; though others have not; and that answers appear to have been provided for some of the doubtful issues. We have endeavored to develop a unified and logical concept of the syndrome as a physiologic response to irradiation injury, attempting to segregate pure effects of irradiation from those secondary to anorexia, vomiting, diarrhea, infection, etc.

Methods

Healthy, adult, mongrel dogs were used, females being preferred. The animals, dewormed and vaccinated against distemper, were observed for at least six weeks before irradiation. During this period basal studies were made. Whenever a new diet* was introduced, at least two weeks were allowed for equilibration.

A calculated tissue dose of 450 - 550 r was delivered to the dorsum of each animal which was snugly encased in an adjustable 3/8 inch plywood box. A 250 KV 25 ma x-ray machine was used at 125 cm from the bottom of the box.

We made balance studies of potassium, sodium, chloride, and nitrogen for 11 to 15 days before irradiation, and thereafter throughout the post-irradiation syndrome. Fecal excreta, collected in large covered jars over several day periods, were kept covered with alcohol and were acidified with H_2SO_4 to prevent loss of nitrogen. After drying and grinding, aliquots were taken for analyses. Urine, drained into flasks containing H_2SO_4 , was collected at a definite time each day and was made up to 1000 cc with the distilled water used to wash the collecting pan. Quantitative recoveries of electrolytes and nitrogen were made in this

* Two types of food were used: "Purina" dog chow in dry compressed pellets purchased on the open market, and a moist meat food specially prepared for us and packed in sealed cans by the Hill Packing Co., Topeka, Kansas. This latter food, ordered in large lots, was found upon analysis to be uniform in composition. It contained 10 per cent protein and 2 to 3 per cent fat.

manner. Vomitus could usually be collected as a separate uncontaminated sample, inasmuch as emesis occurred only for short periods following irradiation. Formed stools, collected in periods demarcated by carmine ingestion, were easily separated from the urine; and even mushy stools which passed through the wire-mesh floor of the cage remained in a small area on the collecting pan and could as a rule be taken up separately.

Water balance determinations were made on adult female dogs. Food and water were offered ad libitum. Only animals with stabilized weight were irradiated. Each day's water intake was measured, and to this amount was added water of food ingested and water of metabolism (taken as 20 per cent of the dry weight of the food.) Inasmuch as it had been determined previously that fresh formed stools contained a nearly constant percentage of water, the dry weight of stool was utilized to calculate the water content. Urine, voided on clean paraffined pans, drained into flasks with a loss of 1 to 3 per cent of the total volume. In determining the total water available for respiratory loss, urine and fecal water was subtracted from the total intake, and to this was added the amount of weight lost. This calculation is based on the assumption that all of the weight lost was water -- an assumption that is not entirely correct and introduces a small, unimportant error.

Total body water was measured by antipyrine* (25), and plasma volume by means of Evans Blue (T-1824)# (26).

Both stool and food were prepared for analysis by digestion with 4N H₂SO₄ to black gummy residues, following which they were ashed overnight at 500-550 C. The ash was dissolved in water with the aid of a few drops of concentrated HCl and was made up to volume. Potassium and sodium measurements were made with a

* Generously supplied by Eli Lilly and Company

Contributed through the courtesy of Eastman Kodak Company.

Beckman flame photometer. Chlorides in blood and urine were measured by the method of Sendrow as modified by Van Slyke and Hiller (27). The Sunderman modification (28) of the method of Van Slyke was used for chloride analyses of stool and food. A correction factor (which remained constant) was necessary to correlate between the methods. Nitrogen was determined by the micro-Kjeldahl technic of Hiller (29), except that the distillate was collected in boric acid and titrated with HCl.

Calculations

The calculations employed followed closely those of Winkler and Elkington (30), and Darrow (31). The external chloride balance, Cl_b , was used to determine the amount of extracellular fluid loss, E , by means of the formula $Cl_b/Cl_e = E$ (Cl_e being the concentration of chloride in extracellular fluid). Sodium excreted from extracellular fluid loss, Na_E , was approximated by multiplying the concentration of sodium in extracellular fluid, Na_e , by the volume of extracellular fluid: $Na_E = Na_e \times E$. The value Na_E was subtracted algebraically from the total external sodium balance, Na_b , to determine the excess excretion or retention of sodium in relation to that anticipated from chloride excretion. Potassium was assigned to the intracellular space only, inasmuch as corrections of the external balance for the amount derived from loss of extracellular fluid were negligible compared to the relatively enormous amounts derived from loss of intracellular space. Loss of cellular mass was calculated by subtracting extracellular fluid from weight loss. These calculations were simplified by the observation made by ourselves and others, that the concentrations of potassium, sodium and chloride do not change in plasma during the syndrome beyond normal diurnal variations. In making the calculations, it was assumed for convenience that chloride occupies an extracellular position only. Although that assumption is not entirely correct,

the results obtained on that basis are believed to be sufficiently accurate to justify its use. The validity of the data obtained in this way was substantiated by the manner in which potassium excretion checked with nitrogen excretion, and by a direct study (to be reported in the second part of this investigation) of electrolyte disturbances in individual tissues. Chances for error were greater in those calculations which depended on measurements of weight. For instance, calculated cellular mass loss included not only the loss of water, ion, and nitrogen-rich tissue, but also loss of fat and hair, and errors due to variability in contents of intestines and bladder.

Results and Discussion

Typical hemorrhagic syndromes were produced which as a rule resulted in death within three weeks. Anorexia was variable in degree and extent, being delayed and less pronounced in animals which ingested palatable meat food, as compared to those which were kept on checker diet. The meat diet was often taken in normal quantities until a day or two before death. Fever occurred with the onset of anorexia. Vomiting was usually observed to occur once in the first 24 hours after irradiation. Mushy rather than frank diarrheal stools were the rule. At times there was a bloody mucoid discharge from the rectum; otherwise, external bleeding was limited to occasional hemorrhages from the uterus. No gross infections were noted at autopsy, but ulcerations, petechiae and ecchymoses of the oral and nasal mucous membranes were seen, as well as petechiae and superficial ulcerations in the stomach, in the ileocecal area, and (inconstantly) throughout the rest of the intestinal tract. Petechiae and ecchymoses were also observed in the retroperitoneal area, heart, lungs and periadrenal fat.

Water Balance. Total body water was reduced after irradiation in most of the animals. It had been observed that in health plasma volume bears a constant relation to total body water. This relationship was much more constant and seemed to be more logical than any relation between plasma volume and body weight. As might be anticipated, studies on obese animals profited most from this observation. As the irradiation syndrome progressed, however, plasma water did not participate in total body water reduction, so that in the end plasma constituted an abnormally large proportion of the total water.

Part of the total water reduction may be attributed to loss of water-rich tissue from decreased food intake, and to a lesser extent to breakdown of radio-sensitive tissue. Since plasma (and blood) volume and tissue water remained relatively constant, any remaining loss of water must have occurred diffusely from interstitial fluid. This concept is borne out by electrolyte studies (vide infra).

The reason why interstitial fluid was depleted became apparent after a study of water balance. Water balance was affected by the various degrees of starvation in our normal animals, and of anorexia in our irradiated animals. Both groups were offered water ad libitum. When food was withheld, or when offered food was not eaten, the amounts of water ingested decreased appreciably. Urine output remained unaltered, however, or was only moderately decreased, and what might be considered a maximum reduction was never observed. When the animals did not drink enough to meet basal needs, water requirements were met by depletion of the body's own water stores. A large portion of this water was derived from cellular breakdown of starvation, the remainder coming from the interstitial space. Large amounts of sodium and chloride were excreted in consequence. Table I indicates the amounts of interstitial water and cellular mass lost by irradiated animals as compared with their pair fed controls, calculated on the basis of chloride excretion. The large

amounts of both modalities excreted by the irradiated group were due presumably to increased metabolism from fever, to breakdown of radiosensitive tissue, and possibly to oligodipsia.

In calculating water losses, weight loss had to be taken into consideration, since that represented available water. Loss of water from the respiratory tract varied considerably in both healthy and irradiated dogs eating a full diet (range of water loss: 0.77 to 1.4 gm per kg per hr.), whereas healthy starved or irradiated anoxic animals showed much less variation (range: 0.57 to 0.87 gm per kg per hr., with a value of about 0.85 for the majority of the dogs.) It would appear that in starved and anorexic animals a fairly uniform basal state of respiratory water output was established, which did not differ greatly from animal to animal, as was true also for relations among ions excreted (vide infra). Indeed, the variations which we observed might have been even less had water losses been expressed in terms of total body water or pulmonary exchange of water, rather than in the more conventional terms of body weight. Also, during control periods our animals doubtless lost considerable amounts of respiratory water from excitement, playfulness, panting, etc. It is noteworthy that irradiated dogs lost more total body water than did their pair-fed partners, although losses from the respiratory tract were the same in healthy and in irradiated animals under similar conditions of environment, activity, and food intake.

Clinically, it appears that water intake is a function of amount of food ingested, as well as a function of metabolic need. Water consumption is reduced in both enforced starvation and irradiation anorexia. It is probable that under these circumstances water lost from the respiratory tract represents not only water taken from the extracellular compartment (which drinking would replace) but also water obtained from starvation breakdown of tissue.

Weight loss. Prior to anorexia, irradiated animals and their pair-fed partners lost approximately equal amounts of weight (average: 0.4 per cent of

the original body weight per day), but after the appearance of anorexia, irradiated animals lost weight more rapidly than their pair-fed counterparts (2.6 per cent per day as compared with 1.5 per cent per day). Total weight losses in 5 irradiated and 5 pair-fed non-irradiated dogs measured: 15.7 vs 11.6 per cent; 8.0 vs 4.7 per cent; 20.5 vs 9.0 per cent; 12.8 vs 4.3 per cent; and 17.0 vs 9.0 per cent. Anorexia and resultant weight losses were delayed and less pronounced in irradiated animals on palatable meat diet, in contrast to those kept on dry pellet diet. When irradiated dogs consumed normal amounts of food*, as little as 3 per cent of the original body weight was lost in 12 days.

External Balance. The excretion data obtained on 6 dogs following irradiation are shown in Table II. These animals all had been well equilibrated prior to irradiation in respect to weight, nitrogen balance, and electrolyte balance. Before the onset of marked anorexia, chloride balance was negative in only two instances, while both sodium and potassium were in negative balance in every instance. After anorexia all three ions were in negative balance. The degree of negativity is shown in Table I in which irradiated animals are compared with their pair-fed partners. As might be anticipated from weight losses, the irradiated dogs lost the larger amounts of both potassium (cellular mass) and chloride (extracellular fluid).

From the total data on all the animals, it was calculated that 10.6 kg of cellular mass was lost altogether, and that there was a collective negative potassium balance of 911 mEq. That is to say, on the average, 86 mEq of potassium were lost for each kg of calculated cellular mass loss. This value may be compared with our observed value of 90-95 mEq for muscle. Indeed, the only low value (61 mEq) obtained was in a dog which bled profusely from the uterus. In this instance the external fluid balance received from whole blood a fluid less rich in chloride than the fluid derived from the interstitial compartment (80 mEq vs 107 mEq).

* Thus, one animal which ate fully until the day of death lost only 0.3 kg over the entire 12 day syndrome. Ion loss was then proportionately low: k, -11 mEq; Na, -11 mEq; Cl, 17 mEq.

The hemorrhage had the effect of making the calculations of loss of extracellular fluid too low, and hence the calculated values of potassium per kg of cellular mass loss were too low also.

In terms of anticipated values for potassium, the data were less variable during anorexia alone than during the entire post-irradiation period. Sodium and chloride were also excreted during anorexia in relative amounts which approximated the proportions normally seen in extracellular fluid. As was true for water balance (vide supra) ion balances during anorexia approached a basal state of metabolism. Another influential factor, however, was that the relatively large weight losses tended to reduce errors of weighing upon which the calculations depended, and at the same time the total amount of ions to be measured were increased. The correspondence between measured and anticipated potassium values enhanced the feasibility of using chloride balance as an index of extracellular change.

When similar calculations were used for nitrogen, the loss was observed to be 34.7 ± 5.3 gm per kg of cellular loss. This mean is close to the theoretical value of 36 gm of nitrogen per kg of muscle.

Studies were also made of the relation of potassium excretion to nitrogen excretion in irradiated dogs. To simplify balance calculations, it was assumed that all potassium and nitrogen were derived from tissue breakdown, and minor quantities of these substances occasioned by loss of extracellular fluid were ignored. Hemorrhage contributed small amounts of potassium and large amounts of nitrogen to the excretion data; they were taken into account in making the calculations. In most instances the observed ratio (2.75 ± 0.3) of potassium balance (in mEq) to nitrogen balance (in gm) approximated that seen in the tissues (our value for muscle was 2.8). This relationship was more accurate and informative

than the relation of either potassium or nitrogen to weight loss or to calculated cellular mass. Urine K/N ratios tended to parallel the nutritional status of the animal. During the control periods, they were similar to that of food ingested (urine 1.49 $\pm$ 0.09; food 1.45); after irradiation, even with normal food intake, the urine K/N ratios may have risen slightly (1.63 $\pm$ 0.11); with anorexia they approached 2.8 (2.68 $\pm$ 0.35). Similar K/N ratios were observed in irradiated and control dogs fed equivalent amounts of food. These ratios approached 2.8 slowly after the development of anorexia in irradiated pellet-fed animals, inasmuch as nitrogen from the food that had been ingested continued to be excreted in urine for two days after the animals stopped eating. A similar delay was noted in healthy animals purposely starved after having been on a pellet diet, which implied that the slow absorption and excretion of this food nitrogen was not a result of irradiation of the gastrointestinal tract. Animals eating moist meat food developed 2.8 ratios promptly after the appearance of anorexia, which indicated comparatively rapid and complete intestinal absorption. Daily excretions of fecal nitrogen were the same for animals on both sorts of diet. There was no increase in nitrogen excretion by this route even in the presence of normal food intake.

Sodium balance (Table II) was always negative after irradiation in spite of relative retention of chloride in some instances. This finding precluded the possibility that excreted sodium was derived entirely from the extracellular space, although following anorexia its relation to excreted chloride was approximately that found in extracellular fluid. It was interesting to correlate sodium excretion with muscle sodium as the syndrome progressed. Muscle sodium was found to be depleted in nearly every animal shortly after irradiation. This was not easy to explain. It seemed unlikely that sodium would appear in the external

balance in larger amounts than would be expected from the chloride balance, since conditions during the syndrome in dogs did not seem to be conducive to muscle sodium loss. Sodium loss in vomitus was small. The mushy stools contained more electrolytes than normal (potassium 2 times normal, sodium 1.5 - 5 times normal, chloride 1.2 - 3 times normal), but the stools were not frequent enough nor bulky enough to account for the sodium depletion; in particular, they would not account for selective depletion of sodium. Furthermore, in these situations of abnormal electrolyte loss, it was noted that renal excretion of electrolytes was usually reduced in proportion. Thus the defenses of the kidney also tended to oppose selective obligatory loss of sodium. And finally, none of the body tissues was found to become sodium-rich without concomitant acceptance of chloride. It would be informative in a study like this to administer radioactive sodium and trace its movements after total body irradiation.

Interpretation and Conclusions

Total body water was reduced following irradiation as a natural response to oligodipsia, decreased food and water intake, and consequent loss of tissue mass. Obligatory evaporative water loss is believed to have been essentially the same for starved healthy animals and anorexic irradiated animals, although it is possible that an occasional irradiated animal, because of reduced activity, had decreased respiratory water loss. In the face of reduced intake and normal output of water, it is concluded that water for respiratory loss was met by tissue breakdown and attendant depletion of extracellular fluid. Tissue water analyses showed that dehydration was not present to any important degree (32). The normal K/N ratios in our balance studies are another indication that significant dehydration was not present (33). Part of the water excreted in excess of the amount

anticipated from tissue breakdown was probably lost as a result of fever per se (34). The extracellular fluid loss also accounts for the large chloride excretions observed, and it is not necessary to incriminate irradiation. This conclusion is supported by the absence in our animals of any acid-base disturbance or shift of chloride ions; on the contrary, chloride concentration in the major tissues of the body (32) and in serum remained remarkably constant. It is interesting that plasma volume increased in the face of extracellular fluid loss, although such increases are consistent even with appreciable dehydration (35).

Our external balance studies showed that irradiated animals lost more electrolytes and nitrogen than did healthy animals given equivalent food intake. Potassium and nitrogen appeared to be excreted in the same ratio as obtains in tissue. Chloride, insofar as it is a measure of extracellular fluid, maintained its integrity. Sodium was a less reliable measure of extracellular fluid since, in the external balance, it did not maintain the relation to chloride normally seen in extracellular fluid. Sodium is the possible exception to the conclusion that significant depletion of water (in the sense of dehydration) did not occur, or that depletion of electrolytes (in the sense of altered relation to each other) was not observed. Our failure to detect retention of sodium, as Bennett (14) did, was probably due to the fact that we employed a different species of animal and did not use radiosodium. Of course, radioactive ions measure different functions, and anorexia can affect exchange and excretion of such ions independently of balance studies. Such observations have been made in connection with potassium in anorexia (36). Edelman (16) who did not use isotopes, found increased sodium excretion in rats. In a study paralleling ours, Phillips and associates (20) observed the effects of nitrogen mustard poisoning in dogs. Although histologic and chemical changes were noted which were similar in some respects to those seen in the x-radiation syndrome, these investigators also reported increased

water intake, inconstant pronounced relative retention of sodium, and excretion of more potassium than could be accounted for by nitrogen studies. These latter findings are in contrast to ours. The conclusions of these workers in regard to loss of extracellular water are similar to ours, however, in that the loss is attributed to a considerable extent to reduced water intake, and not primarily to the injurious agent per se.

We have concluded that after irradiation our animals were able to handle large amounts of ingested protein, very much as they did before irradiation. Excretion of nitrogen in stools was not increased, no delay in nitrogen absorption was detected, and body weight was well maintained when adequate food was ingested. The implication is clear that, given a high protein diet, the irradiated dog is able to convert protein into energy and maintain caloric balance. It follows, from a therapeutic standpoint, that a palatable diet should be offered with the expectation that it will be ingested, absorbed, and metabolized in a virtually normal manner. Although increased catabolism results in abnormal losses of weight, water, electrolytes, and nitrogen, the irradiated animals do not become dehydrated appreciably, nor do they exhibit ionic imbalance induced by irradiation beyond that which can be accounted for by anorexia, variable degrees of vomiting and diarrhea, fever, and infection.

SUMMARY

A study has been made of effects of acute total-body irradiation upon water, electrolyte, and nitrogen balances in dogs in which typical hemorrhagic syndromes were produced.

A brief resume of previous work done on this subject is presented.

The main abnormalities observed by us were:

- (1) Reduced total-body water without significant dehydration;
- (2) Small decreases in blood volume, the decreases incident to reduction of red cell mass being countered by moderate increase in plasma volume;
- (3) Decreased water intake with nearly normal water losses, the resultant water deficit being compensated for mainly through tissue loss and diffuse loss of extracellular fluid;
- (4) Weight loss, more pronounced in animals on dry pellet diet than in those on palatable meat-rich diet, due to delayed onset of anorexia in the latter group;
- (5) Negative sodium and potassium balances throughout the syndrome; inconsistently negative chloride balance before the onset of anorexia, and consistently negative chloride balance after anorexia;
- (6) Increased K/N balance ratio which, after anorexia, approached the K/N ratio of muscle;
- (7) No evidence from external balance studies of acid-base disturbance, or of gross depletion or internal shift of potassium, sodium, or chloride.

When irradiated animals were offered moist, palatable, high-protein diet, anorexia was delayed, often until shortly before death. Prior to anorexia, digestion, absorption, and metabolism of nitrogen proceeded in a nearly normal manner. Therapeutic implications of this observation are obvious.

Indeed, most of the observed effects of irradiation upon water, electrolyte, and nitrogen balances can be accounted for largely on the basis of anorexia, oligodipsia, vomiting, diarrhea, fever, infection, etc., and need not be attributed to any significant degree to the primary effects of irradiation itself.

TABLE I. Comparative Balance Studies between Irradiated Anorexic Dogs and their Pair-fed Controls

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Group	Dog	Duration of Anorexia Days	Diet	Changes in extra- cellular fluid vol. Based on		Changes in cell mass Kg.	K bal. during anorexia mEq	Total K bal. post- irrad. mEq	Fate of animal
				Cl bal. Kg.	Na. bal. Kg.				
I.	Pair-fed	5	Moist, high-prot.	- 0.45	- 0.58	- 0.65	- 44	- 84	Died
	Pair-fed	5	Pellet	- 0.31	- 0.42	- 0.94	- 56	- 60	
	Irradiated	5	Pellet	- 0.65	- 0.61	- 1.07	-106	-124	
II.	Pair-fed	7	Moist, high-prot.	- 0.57	- 0.44	- 1.2	- 73	- 82	Died
	Irradiated	7	Moist, high-prot.	- 0.25	- 0.35	- 1.45	-161	-207	
III.	Pair-fed	4	Moist, high-prot.	- 0.22	- 0.23	- 0.38	- 30	- 54	Died
	Irradiated	4	Moist, high-prot.	- 0.38	- 0.34	- 0.46	- 55	-110	
IV.	Pair-fed	5	Pellet	- 0.74	- 0.57	- 1.08	- 97	- 97	Died
	Irradiated	5	Pellet	- 1.91	- 1.48	- 1.64	-144	-144	
V.	Pair-fed	7	Moist, high-prot.	/ 0.05	/ 0.24	- < 0.1	- 8	/ 6	Survived
	*Irradiated	7	Moist, high-prot.	- 0.09	- 0.36	- 0.15	- 14	- 23	
VI.	Irradiated	3	Moist, high-prot.	- 0.22	- 0.28	- 0.75	- 83	-124	Died
VII.	Irradiated	8	Moist, high-prot.	- 0.80	- 1.43	- 2.5	-153	-179	Died

* This animal's anorexia reduced food intake to one-third of normal.

TABLE II. EXTERNAL IONIC BALANCES FOLLOWING IRRADIATION

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Dog #	Period of Observation Days	Food		External Balance			Weight Changes			Ratio K/CML *
		Type	Intake	K	Na	Cl	Total body	Extracellular	Cellular	
				mEq	mEq	mEq	weight Kg	fluid Kg	Mass Kg	
30	6	Pellet	Partial anorexia	- 18	- 5	/ 11	- 0.50	/ .09	- 0.59	30.5
	5		Total anorexia	-106	- 96	- 77	- 1.72	- .648	- 1.07	100
(Total)	11			-124	-101	- 66	- 2.22	- .558	- 1.66	75
36	5	Pellet	Total anorexia	-144	-234	-225	- 3.55	- 1.91	- 1.64	89
20	12	Moist, high-prot.	Full intake	- 41	-121	/ 18	- 0.48	/ .152	- 0.63	65
	3		Total anorexia	- 83	- 44	- 26	- 0.97	- .221	- 0.75	111
(Total)	15			-124	-164	- 8	- 1.45	- .070	- 1.38	89
21	12	Moist, high-prot.	Pre-anoxic	- 26	- 39	/ 14	- 0.35	/ .116	- 0.47	58
	8		Total anorexia	-153	-188	-107	- 3.4	- .905	- 2.5	61
(Total)	20			-179	-227	- 94	- 3.75	- .789	- 2.97	60**
27	11	Moist, high-prot.	Pre-anoxic	- 46	- 34	- 36	- 0.8	- .307	- 0.5	93
	7		Total anorexia	-161	- 55	- 30	- 1.7	- .254	- 1.45	111
(Total)	18			-207	- 89	- 66	- 2.5	- .561	- 1.95	106
29	7	Moist, high-prot.	Partial anorexia	- 55	- 78	- 69	- 1.11	- .583	- 0.53	104
	4		Total anorexia	- 55	- 53	- 45	- 0.84	- .377	- 0.46	119
(Total)	11			-110	-131	-114	- 1.95	- .960	- 0.99	111

* Ratio of Potassium loss (in mEq) to Cellular Mass Loss (in Kg)

** This value was low because the animal lost 20 per cent of its total blood volume in hemorrhages from the uterus.

Included in the derived data, it made calculations for E too low and for CML too high, lowering the K/CML Ratio.

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