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Post-Irradiation Syndrome in Humans

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ABSTRACT

The report discusses the alterations induced by total body irradiation in patients and in dogs in terms of clinical and hematological findings, lipoproteins, and electrolytes.

Studies were made of five patients, selected for their relatively good condition, who received total body irradiation of 150 r (except for one case receiving 85 r) delivered to the body through four ports and generated by a 1 Mevp Resonant generator. Case reports of clinical and hematological findings discuss the range of depression of total white cells and platelet count, and observations of clinical reaction. Only two patients showed evidences of abnormal bleeding in association with low platelet counts.

The rationale for detailed lipoprotein analyses of the post-irradiation state is derived from animal experiments indicating a post-irradiation block in the serial conversion (clearing activity) of larger to smaller lipoproteins as part of the normal fat transport system. The report describes methods used for separating lipoproteins from serum, their subsequent fractionation into three components, and determination of cholesterol content. The results of lipoprotein determinations are presented for the five patients in terms of changes in clearing activity.

The report of studies of electrolytes deals with two approaches exploring possible modifications of cellular membrane activity produced by total body irradiation. One involves the rate of exchange of potassium between the extracellular and intracellular phase and the other, the glucose assimilation coefficient. Methods of determination are set forth. Two different syndromes resulting from massive total body or head irradiation of dogs are described. In addition, studies have been made in irradiated dogs of the alterations in the mechanisms of transport of electrolytes from the lumen of the bowel to the plasma. In the post-irradiation state, the constancy of sodium transport from plasma to lumen ceases while the passive diffusion of sodium from lumen to plasma increases sharply resulting in greater loss of total electrolytes from the lumen.

PROGRESS REPORT

Introduction

For the purposes of organization, this report is divided into three major sections: I) Hematology and clinical findings, II) Lipoprotein studies, and III) Electrolyte studies.

Selection of Patients

It was felt that only patients with widespread neoplastic disease were acceptable for this study. This is not an ideal group to compare to healthy young males. To make this differential as small as possible, the following rigid requirements were adhered to before accepting a patient for this study.

1. General chemistries

   a. Electrolytes, including sodium, potassium, chloride, CO_2, phosphorus and calcium, should be within normal limits.

   b. Liver function should be biochemically within normal limits as evaluated by bilirubin, bromsulphalein retention, cephalin floculation, thymol turbidity, cholesterol, both total and esters, protein, albumin, prothrombin time and alkaline phosphatase. Elevations in the alkaline phosphatase would be acceptable if it could be shown that this was on the basis of osseous metastases. Slight deviations from normal liver function studies are acceptable if these are established as part of a long-standing chronic process.

   c. Renal function studies preferably should be within normal limits; however, if there is no reflection of abnormalities in the electrolyte studies mentioned above, a decreased GFR as evidenced by an elevated blood urea nitrogen or blood non-protein nitrogen is acceptable.

2. Hematology

   All patients should have normal values for hemaglobin, hematocrit, RBC, WBC, differential and platelets. Bone marrow aspiration should be within normal limits.

3. Particular neoplasms not acceptable.

   a) Functioning endocrine tumors.

   b) Leukemias.

   c) Polycythemia vera.

   d) Lymphomas, unless all the above criteria are fulfilled. In addition, if such rapid breakdown of neoplastic tissue should occur following total body irradiation that there is a significant rise in the plasma uric acid, this case would not be included.

   e) Multiple myeloma.

   f) Any primary lesion metastatic to the pituitary or hypothalmus.

4. Metabolic condition of the patient.

   Patients exhibiting bizarre metabolic disorders were not included in this study.

In addition to those considerations:

   a) The patient should be able to maintain fluids and nutrition by mouth.

   b) All endocrinopathies should be ruled out.

   c) Patient should not be on drugs such as chlorpromazine, cortisone, dramamine or any other agent which might mask the clinical syndrome following total body irradiation.

Method of Irradiation

All irradiations were done with the Mevp Resonant generator at a TSD of 290 10 cm and a dose rate of approximately 6 r/minute. The irradiations were accomplished through four ports, upper and lower half of the body, anterior and posterior with attention being given to the panumbra and overlap of the upper and lower fields. This resulted in essentially a uniform dose distribution throughout the body.

I. Clinical and Hematological Findings

During the year five patients received total body irradiation. Of these, three were females and two were males. Two of the patients had generalized lymphoma, one had anaplastic sarcoma--cell type undertermined, one had inoperable adenocarcinoma of the stomach, and one patient had two primaries, carcinoma of the lip with pulmonary metastases and adenocarcinoma of the kidney. All patients were in fair to good general condition at the onset of treatment.

The data for platelets, lymphocytes, and granulocytes are shown in Figures 1-5.

Case Reports

The patient (J.S.) receiving the lowest exposure was given 85 r total body irradiation. This patient had lymphoma with the presenting symptoms of severe unrelieved pruritus, moderate anemia, leukocytosis, normal platelet count. Post-treatment values indicated moderate depression of the white cell count from pre-treatment values, reaching a low of 0.5×10^3 cells on the 59th day. There was a broad period of depression ranging from the 43rd day to the 70th day, at which time the count again returned to about 2,000. Platelet count also became severely depressed on about the 40th day, reaching a value of less than 20,000 cells per cubic millimeter. This did not recover until the 75th day, at which time the count was greater than 100,000. On the 43rd to the 48th day the patient had purpura and bleeding. She received multiple fresh whole blood transfusions during this time and recovered without untoward sequelae.

It is interesting to note that in spite of inability to relieve her presenting, incompacitating complaint by any of the chemotherapeutic agents or by partial body irradiation, she had substantial relief for approximately three months following total body irradiation.

In spite of the relatively low dose, this patient had marked and severe depression of the white blood cell and platelet elements. It is our current belief, as yet unproven, that prior local radiation and chemotherapeutic agents, as it were, prepared the soil for the insult received from total body irradiation and contributed to its effect. Both the severity and the duration of this patient's depression, in our opinion, were more than could reasonably be attributed to 85 r total body irradiation.

Four patients received 150 r TB measured in air at the midplane. One of the patients (W.H.), within one week after completion of radiation developed symptoms of partial gastric obstruction which subsequently proceeded to complete gastric obstruction and a severe metabolic alkalosis. Subsequently it was determined that an entirely asymptomatic metastasis from his carcinoma of the kidney had obstructed the duodenum producing the above symptoms and ultimately being responsible for the patient's death. The total body irradiation did not modify the course of this patient's illness in any way, either adversely or favorably. However, because of this complication which was accompanied by bleeding, the hematological data in this patient are removed from further discussion.

Another patient (S. P.), a 40 year-old white female, was admitted with a diagnosis of carcinoma of the ovary with widespread intra-abdominal and intrathoracic metastases. Biopsies taken at this Institution were interpreted as sarcoma, origin and cell type undetermined. The general condition of the patient was good and she was subjected to total body irradiation. There was no subsequent improvement in her clinical condition. However, her sarcoma was highly aggressive and growth rate was rapid. The white blood cell count showed a drop beginning on the 18th day post-treatment, reaching its minimal value at the 32nd day. There was a rapid return to normal values by the 44th day. In accordance with the pattern seen in earlier patients the lymphocyte count dropped more rapidly than did the polymorphonuclear count, the lymphocyte count reaching approximately 50% of the pre-treatment values by the 4th-6th day and remaining low throughout the period of observation, in this instance 60 days. The polymorphonuclear drop did not begin until the 18th day and also reached its minimum on the 32nd day.

Platelet counts were substantially in the pre-treatment range until the 22nd day when they fell rapidly reaching a value of less than 10,000 on the 24th day. The values then remained at less than 100,000 until the 42nd day.

On the 30th day the patient developed epistaxis and minimal purpura. The clotting time was elevated to 19 minutes. The patient was then given 50 milligrams of protamine zinc sulphate with prompt subsidence of the bleeding diathesis. The clotting time was within normal limits when it was determined three days later.

This sequence is perhaps worth additional comment. The rationale for giving the protamine sulphate was based primarily upon the lipoprotein studies discussed elsewhere in this report. It will also be recalled that Drs. Jacobson and Allan (J.A.M.A., 139, p. 1251, 1949) have reported upon radiation-induced hemorrhage in laboratory animals, and felt that protamine sulphate had exerted a beneficial effect in that setting. Because in the estimation of the investigator the patient's clinical condition could be disastrously influenced by moderate to severe bleeding, it was deemed wiser to attempt to correct any hemorrhagic tendency rather than to observe the unmodified syndrome. Protamine sulphate was therefore given because of the foregoing observations and, while we cannot put forward anything other than the suggestion that there may be a cause and effect relationship, it is our unanimous feeling here that the observation is worth pursuing further in patients with similar abnormalities. An attempt will be made to correlate these with the lipoprotein observations.

Another patient (K. H.), an elderly white female, with adenocarcinoma of the stomach which was locally unresectable but who was in excellent general condition in spite of her advanced disease, received 150 r total body irradiation. The pattern here of response was somewhat different from that reported just above. Total white blood cell count showed a relatively early depression reaching half its pre-treatment value by the 6th post-treatment day. The minimal values were reached on the 30th day and were approximately 1/3 that of pre-treatment value. Recovery was slow but steady and it reached 2/3 pre-treatment value by the 56th day.

The lymphocytes showed an early depression to approximately one-half the treatment value. The polymorphonuclear cells did not show an early depression but did show a later one.

The platelet count showed little change until the 17th day post-treatment at which time it declined again to reach its minimum from the 20th to the 32nd day. This value never fell below 40,000 platelets per cubic millimeter. Recovery began on the 35th day and essentially pre-treatment levels were reached by the end of observation on the 49th day.

Clinically, the patient showed no upset from the reaction. There was no nausea and vomiting. Appetite was good throughout the period of observation. No purpura developed. Bleeding and clotting times never exceeded normal limits for this institution.

The last patient (W. J.), to receive 150 r total body irradiation was a young, colored male with disseminated reticulum-cell sarcoma. While the disease was extensive, his general condition at the time he received 150 r total body irradiation appeared to be excellent. There were no immediate symptoms consequent from the radiation. Subsequently, the patient did develop some bleeding from the nose and splinter hemorrhages under the nail beds. However, there was a large tumor deposit here and this could be adequate explanation for the local hemorrhage.

White blood cell count showed the pattern we have learned to associate with 150 r in humans. The minimal value approximately 1/3 of the pre-treatment, was reached on the 28th day, recovery beginning around the 40th day, pre-treatment values not being obtained again by the end of treatment and the period of observation continuing, in this instance, to the 56th day. The absolute lymphocyte count was reduced to one-half pre-treatment value within a few days after the administration of radiation. Polymorphonuclear counts declined more sedately, reaching their minimal values at approximately the 28th-32nd day, beginning recovery on the 56th day.

Platelet counts again adhered to the common pattern, little change being seen before the 16th day, then a relatively abrupt drop to a minimal value on the 22nd day, recovery beginning on the 36th day with a value of 100,000 being exceeded on the 46th day, pre-treatment levels being obtained on the 59th day. Return to pre-treatment levels was a little earlier than has been noted in other patients.

Objectively, there was evidence of diminution in the mass of his reticulum-cell sarcoma. This, however, was transient and there was soon evidence of increased rate of growth in at least some of his tumor deposits.

In summary, then, with the exception of acute and transitory symptoms of nausea and vomiting, only two patients showed evidences of abnormal bleeding in association with their low platelet counts. In one patient this tendency subsided promptly upon receipt of 50 mgm. of protamine sulphate. In one patient there was evidence of objective response in the tumor process.

II. Lipoprotein Studies

Reason for study: In rabbits receiving high doses of total body irradiation, an early increase in the serum turbidity (caused by chylomicrons) is prognostic of lethal damage. More detailed lipoprotein analyses have shown that one to two days after irradiation, there is a block in the serial conversion of larger to smaller lipoproteins which is a part of the normal fat transport system. Since heparin is involved in the "clearing factor" mechanism which is responsible for this conversion, heparin deficiency has been suggested.

Changes in lipid transport following severe whole body irradiation have also been observed in dogs. It therefore seemed important to determine the effect of therapeutic doses on the serum lipoproteins of platelets.

Methods: In the first series, 13 patients were studied. The results of this group were included in last year's report. Three of them were followed through two separate treatments.

In the current series, fasting blood samples were taken before irradiation and one and three days afterward. Additional samples were taken after further intervals of time whenever it was considered necessary, especially when the patient showed thrombocytopenia. The serum was checked for turbidity in the spectrophotometer at 605 m and stored at 4°C. with the addition of 1:10,000 merthiolate for not more than 2 weeks. For the separation of the lipoproteins 7.05 ml. of serum were mixed with 3.45 ml. of NaCl (density 1.1855) to give a solvent density of 1.063. The solutions were then run in the preparative ultracentrifuge for 16 hours at 40,000 R.P.M., at about 10°C. The lipoproteins of density less than 1.063, which were concentrated in the top layer, were collected with a hypodermic needle and specially designed syringe and transferred to a 5 ml. graduate. The volume was recorded and the lipoprotein content measured from the size of the flotation boundaries obtained in the analytical ultracentrifuge by the Goffman technique. The lipoprotein spectrum was separated into 3 fractions, Sf 2-10, Sf 11-20, and Sf 21-100. Occasionally a fourth component, Sf 100-400 was observed. The calculations were made by the procedure described in 1952. The total cholesterol was determined in the whole serum and in the lipoproteins of density greater than 1.063 (found in the lower layers of the ultracentrifuge tubes), and the "low-density lipoprotein cholesterol" calculated by difference. The calculated low-density lipoprotein cholesterol levels were usually fairly close to one-third the total low-density lipoproteins measured in the ultracentrifuge. This agrees with the known chemical composition of these lipoproteins. It, therefore, did not seem necessary to measure the low-density cholesterol directly, since this would necessitate taking considerably larger samples of blood.

Recently, a second series of experiments has been initiated. The alpha and beta lipoproteins are separated by Method 10 of Cohn et al., and the low-density lipoproteins are separated and analysed as described above. Cholesterol and phospholipid are measured on all fractions. Three experiments are reported here; the "high-density cholesterol" in this case represents the alpha lipoprotein cholesterol. A fourth experiment is now in progress.

Results:

The results on the patients studied this year are shown in Figures 5 to 10. One patient, W. H., was studied only on the third post-irradiation day because of the rapid progress of his malignant disease. Of the remaining four, two patients (J. S. and S. P.) showed an early increase in clearing factor, one (K. H.) showed no change, and one (W. J.) showed a decrease in clearing factor early. At the time of the most marked thrombocytopenia (TCP day), three showed an increase in clearing factor, and one showed a marked decrease.

Table 1 summarizes all the data obtained to date on patients who developed a thrombocytopenia and on whom β-lipoprotein determinations were done during the period of the decreased platelets. It should be noted that one patient developed a severe thrombocytopenia and bleeding but lipoprotein studies were not done at that time. It should be noted that only one patient who showed clinical evidence of bleeding did not show an increase in clearing factor. Moreover, the severity of bleeding was approximately proportional to the increase in clearing factor.*

*The clinical aspects of this are discussed more fully under "Clinical Aspects."

Table 1

Patient	Dose	Sex	Diagnosis	Early	TCP day
No clinical evidence of bleeding					
MH	150r	F	Ca Vulva	-	-
KH	150r	F		0	=
Clinical evidence of bleeding					
BC	150r	F	Ca Cervix	0	-
WJ	150r	M	R Sa	-	+
SP	150r	F	L Sa	+	++
JS	85r	F	HD	+	+++
WD	150r	M	Synovioma	0	++

Discussion:

The changes in serum lipoproteins which appear after therapeutic doses of irradiation are of course not as clear as the changes seen in animals after lethal doses. In some patients, clearing activity appeared to have decreased during the week following treatment, while, in others, an apparent increase was seen. Since the circulating lipoproteins represent the balance between lipids added to and removed from the circulation, it would appear that the doses used in these patients can cause this balance to swing sometimes one way and sometimes the other. In rabbits receiving lethal doses, the lipid transport system is usually inadequate for its load. Whether this is the result of a deficiency in the transport or an overloading of the system is still unknown. The many lipid and lipoprotein studies now being carried out on animals in connection with research on atherosclerosis are frequently criticized as not being applicable to human physiology. The same criticism might be levelled at studies of irradiation effects in animals. One valuable result of the findings reported in the present study is, therefore, the observation that the lipoprotein changes found in humans soon after irradiation may be similar to those seen in animals.

The second observation of importance is that several patients who showed clinical evidence of radiation damage had increases in clearing factor activity at the time. If this is the result of hyperheparinemia, it reinforces the suggestion that post-irradiation hemorrhage is also the result of an excess of circulating heparin or heparin-like compound.

III. Electrolytes

A. Human

The objective of this study is to explore the possible modifications of cellular membrane activity produced by total body irradiation. Two approaches have been utilized in this study, the first being the rate of exchange of potassium between the extracellular and intracellular phases, and second, determination of the glucose assimilation coefficient.

In an effort to determine changes in the rate of exchange of potassium, plasma volume was determined by Evans Blue, extracellular fluid by Inulin, and total body water by Antipyrine. Immediately following these determinations, total exchangeable potassium was determined with radioactive potassium 42, emphasis having been placed upon frequent sampling of the plasma so that a "fall-off curve" covering 30 hours time could be accurately constructed. By a modification of the Feather technique, the component slopes, and compartment sizes were determined. This information was then utilized to construct a model the accuracy of which was tested by means of an analogue computer. With this technique, it has been shown in one case that there has been a small, but significant, change in the relative compartment sizes, as well as the rates of exchange of potassium following total body irradiation.

The glucose assimilation coefficient was determined by the techniques of Grievol and Basteni, et al, utilizing the intravenous glucose tolerance test. The modification of Duncan allows for a more accurate determination of the glucose increment index which gives a quantitative determination of any changes in the amounts of glucose which leaves or enters the circulating blood at any given time interval. Blood sugar was determined by the Nelson modification of the Somogyi technique. Again, only one patient has been studied pre- and post-irradiation, and although the glucose increment index was altered by the irradiation, it was not a statistically significant alteration.

B. Dog Studies

1. Total body irradiation

Two groups of dogs have been given large doses of radiation. One group of animals was given 10 or 12,000 r total body irradiation at a dose rate of approximately 35r/minute. Bloods were analyzed at periods following this dose for pH, CO_2, sodium, potassium, chloride, calcium, phosphorus, magnesium and plasma osmolarity. On some dogs, ammonia and blood urea nitrogen were also measured. At this dose of radiation, two different syndromes may be observed in dogs. The first is one terminating fatally in 28 to 31 hours. The syndrome is characterized by neurological signs of cogwheel rigidity, twitching, fine tremors, ataxia and abnormal eye signs. These neurological findings are transitory and will vary from time to time. Hyperventilation is observed, starting a few hours before death. The results of such an experiment are shown in Table 2. As can be seen, the calcium drops sharply from a control of 10.8 mgm percent to 6.0 shortly before death. This occurs as the phosphorus rises from control values of 6.0 mgm percent to 14. A consistent finding is the development of a respiratory alkalosis with pH's as high as 7.50 and PCO_2's as low as 20. In the experiment illustrated, the pH was 7.48 4 1/2 hours before death, and the PCO_2 was 30.8. Another consistent finding is the fall in Cl to as low as 90 and a consistent rise in the plasma osmolarity in excess of what can be calculated from the electrolytes and the normally measured plasma constituents such as glucose and urea. In this laboratory, the rise of osmolarity in excess of calculated is an ominous sign, and is associated always with respiratory alkalosis whether produced by thyroid storm, ammonia infusion, or forced hyperventilation. In the post-irradiation syndrome at these doses, there is no rise in the plasma ammonia, and this cannot be indicted as the cause of the respiratory alkalosis.

The second syndrome observed occurred in some of the dogs. This consisted of a pattern not unlike that seen at doses of 1,000 r and above, namely, diarrhea, vomiting, dehydration and death in 3 1/2 to 5 days. A second group of dogs was given 15,900 r to the head alone. This was delivered with the 250 Kevp machine with a HVL of 1.0 mmcu, and the dose rate was 150r/minute. The dogs convulsed during the irradiation, and convulsions might be expected anytime after 10,000 r. In this setting of irradiation of the head alone, all dogs showed massive convulsions during the first day, with periods of quiet between them. In all cases, a marked respiratory alkalosis developed before the convulsions occurred. The results of a typical experiment are shown in Table 3. Here the pH, while not changing dramatically the partial pressure of CO_2, fell from a normal control of 40 ml. of mercury to as low as 27.8. In this setting there were no changes observed in calcium, phosphorus or other electrolytes until the terminal phase. The terminal changes were those of dehydration. Again, a marked rise in plasma osmolarity was observed as early as 3 hours after the start of irradiation.

Following the first period of 8 hours, the pattern of events varied in different dogs. The characteristic pattern was one of lethargy, rigidity and, on occasion, small tremors. The time to death varied considerably, one animal dying one hour after completion of radiation, and another animal being sacrificed after a 10-day period.

It is not known whether the respiratory alkalosis is the cause of the convulsion or not. It might be noted in passing that in similar settings of respiratory alkalosis, as mentioned above, convulsions of this character are noted.

Efforts are under way at the moment to delineate this problem.

2. Bowel Studies

As reported in last year's report, the normal transport of electrolytes in the jejunum and ilium are characterized by the fact that sodium is transported from the plasma to the lumen of the bowel at a constant rate, independent of the concentration of sodium within the lumen. However, the transport of sodium from the lumen to the plasma would appear to be one of passive diffusion, and is proportional to the concentration of sodium within the lumen.

Three days following 1500 r to the isolated loops of bowel, these mechanisms are severely altered. The heretofore observed constancy of sodium transport from plasma to lumen ceases and transport is inversely proportional to concentration of sodium within the lumen. The transport in the other direction, from lumen to plasma, seems to remain one of passive diffusion. However, the rate is sharply increased. The combination of these two mechanisms results in a much greater loss of total electrolytes from the lumen in the post-irradiation state.

It is reasonable to assume that this loss of electrolytes is in excess of what would be observed in diarrhea from other causes.

The return to normal is variable and whether the differences seen 10 days post-irradiation are significantly different from control values is yet to be established.

Table 2

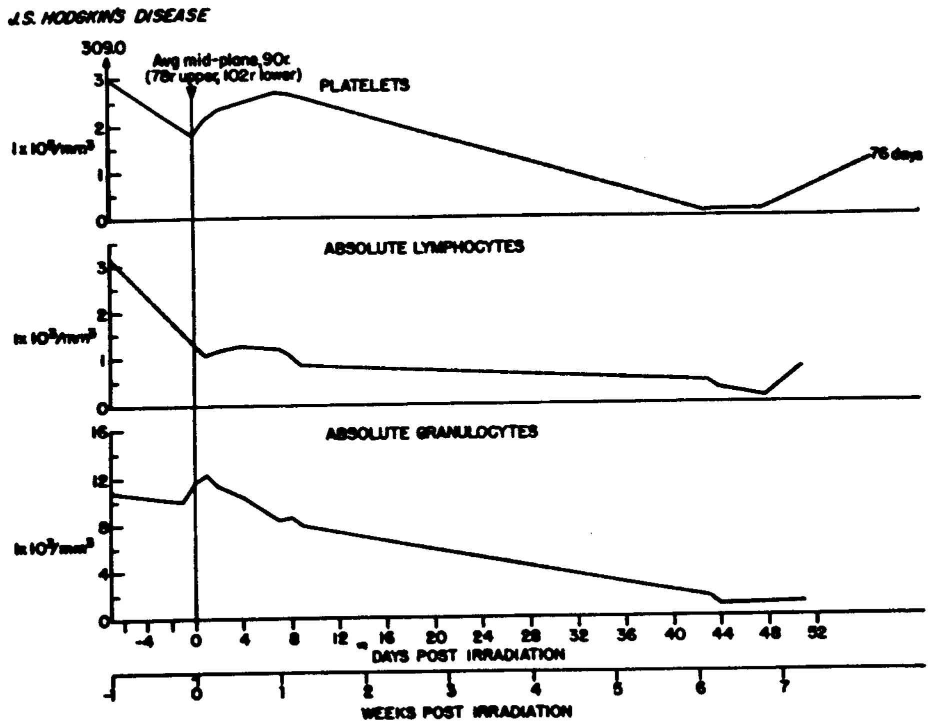
1.2 x 10^4r to Total Body of Dog

Status	Time	pH	CO_2	pCO_2	Ca	P	Cl	OSMOL	Resp
Control	0	7.44	22.3	32.4	10.8	6.00	116	291	24
p̄ 12,000 r	7.44	7.42	18.5	28.8	9.4	9.00	118	302	22
4 1/2 hr. p̄ death	23.7	7.48	23.1	30.8	6.4	12.3	96	316	21
1/2 hr. p̄ death	28.3	7.45	16.2	22.9	6.0	14.0	97	330	154

Table 3

1.56 x 10^4r to Head of Dog

Status	Time	pH	CO_2	PCO_2	Ca	P	OSMOL
Control	0	7.41	26.1	40.5	10.8	4.66	299
Pre convulsion p̄ 12,470r	12.7	7.45	17.8	25.4	11.4	2.80	305
p̄ 15,600r Convulsing	3.25	7.41	18.1	27.8	10.7	2.73	312
Opisthotonos No convulsion	173	7.36	23.8	41.5	10.1	5.20	390


J.S. HODGKIN'S DISEASE
309.0
Avg mid-plane 90r
(78r upper, 102r lower)
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76 days
1 x 10^5/mm^3
ABSOLUTE LYMPHOCYTES
1 x 10^3/mm^3
ABSOLUTE GRANULOCYTES
1 x 10^3/mm^3
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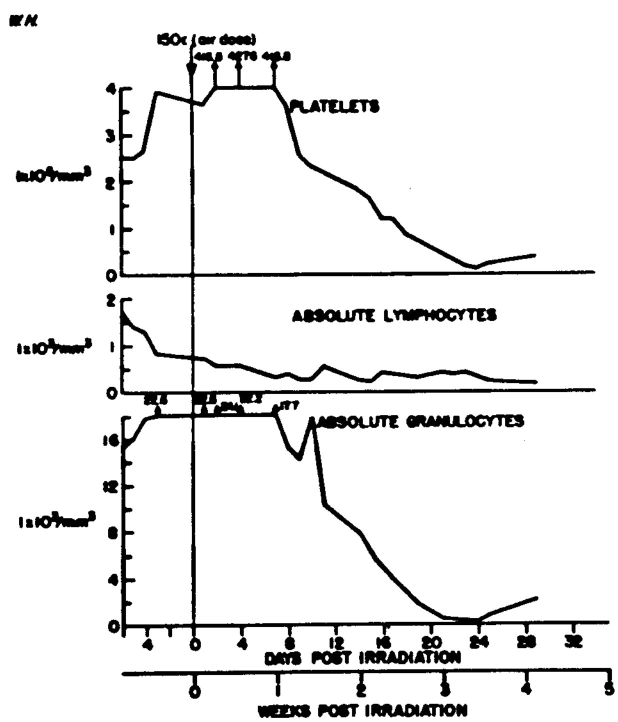
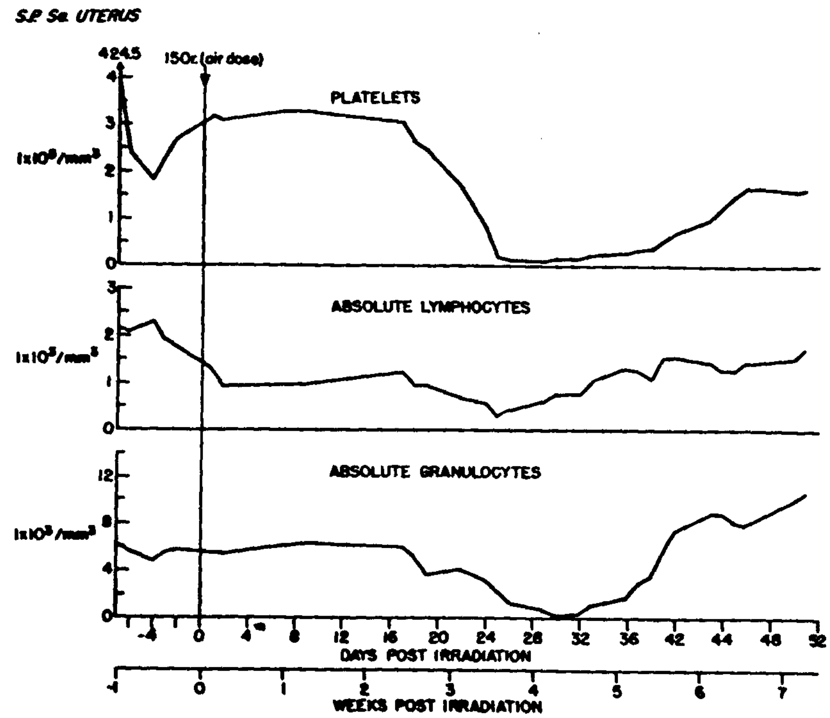
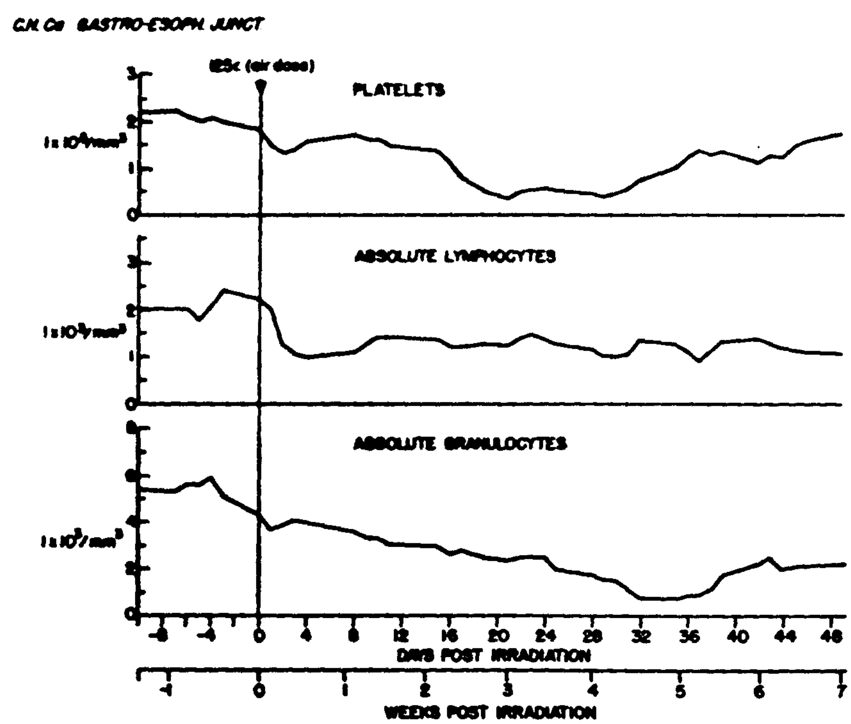
DAYS POST IRRADIATION
-1 0 1 2 3 4 5 6 7
WEEKS POST IRRADIATION

2


W.N.
150r (air dose)
PLATELETS
1 x 10^5/mm^3
ABSOLUTE LYMPHOCYTES
1 x 10^3/mm^3
ABSOLUTE GRANULOCYTES
1 x 10^3/mm^3
4 0 4 8 12 16 20 24 28 32
DAYS POST IRRADIATION
0 1 2 3 4 5
WEEKS POST IRRADIATION

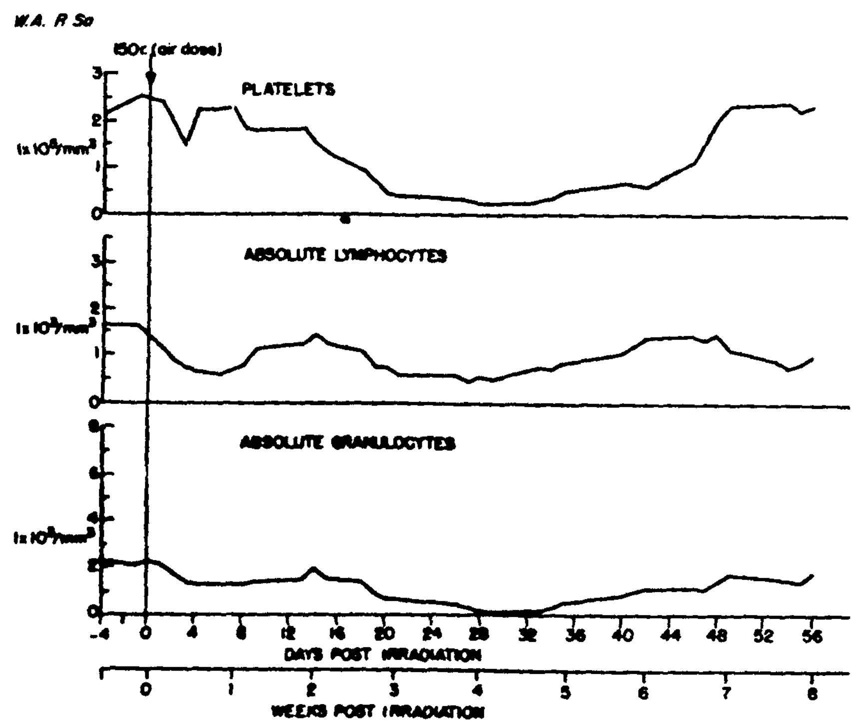


S.P. Sa. UTERUS
424.5
150r (air dose)
PLATELETS
ABSOLUTE LYMPHOCYTES
ABSOLUTE GRANULOCYTES
DAYS POST IRRADIATION
WEEKS POST IRRADIATION

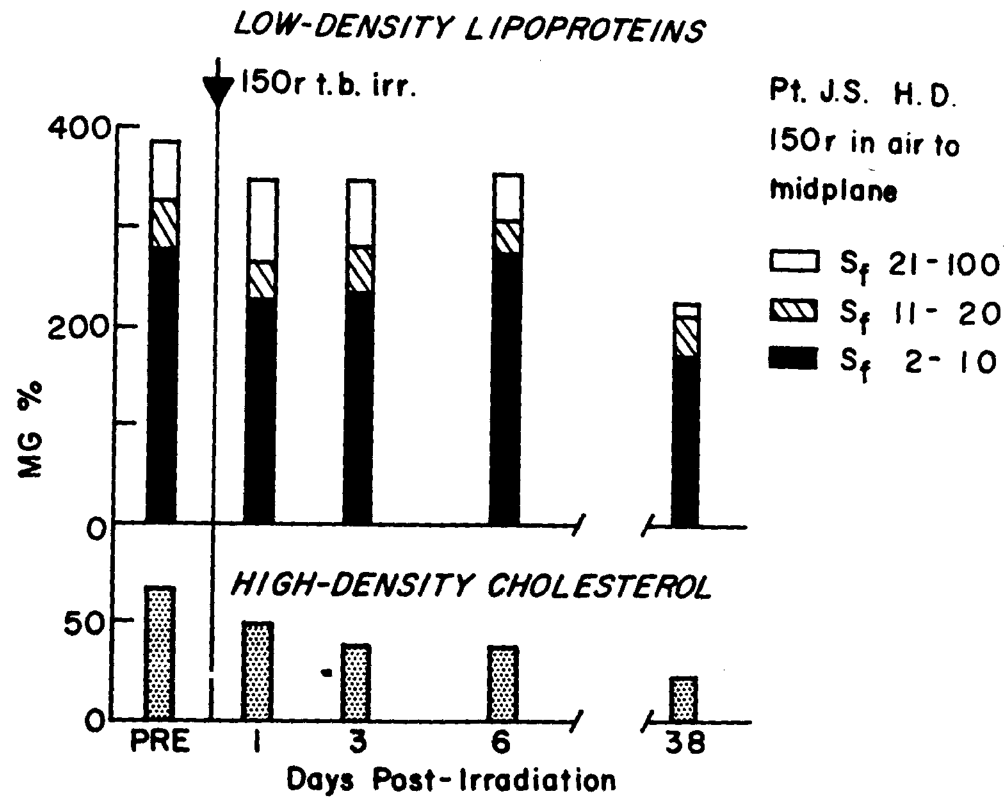


C.H. Ca GASTRO-ESOPH. JUNCT
125r (air dose)
PLATELETS
ABSOLUTE LYMPHOCYTES
ABSOLUTE GRANULOCYTES
DAYS POST IRRADIATION
WEEKS POST IRRADIATION

(5)



W.A. R Sa
150r (air dose)
PLATELETS
(x 10^5/mm^3)
ABSOLUTE LYMPHOCYTES
(x 10^3/mm^3)
ABSOLUTE GRANULOCYTES
(x 10^3/mm^3)
DAYS POST IRRADIATION
WEEKS POST IRRADIATION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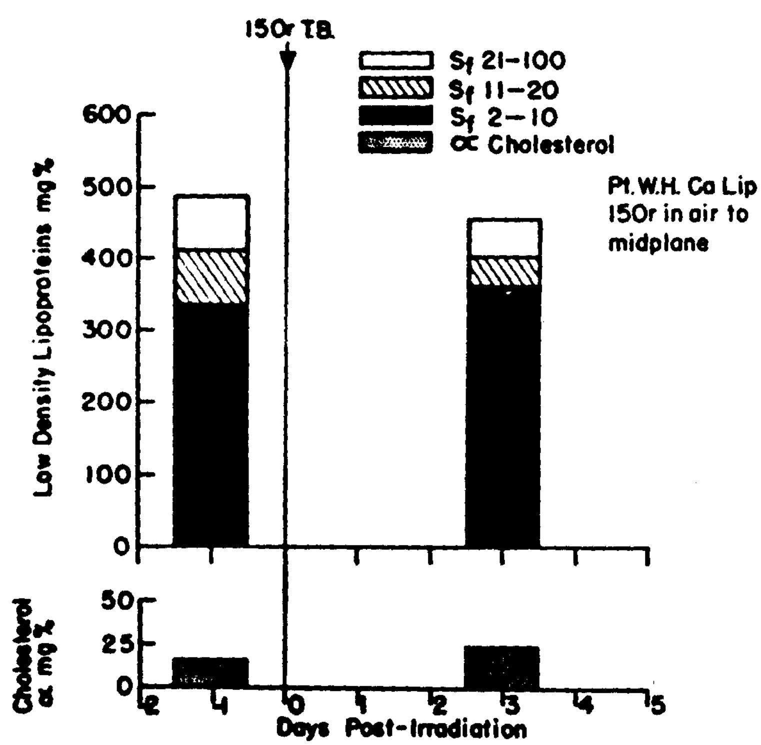
150r in air to
midplane
Sf 21-100
Sf 11-20
Sf 2-10
400
200
0
MG %
HIGH-DENSITY CHOLESTEROL
50
0
PRE
1
3
6
38
Days Post-Irradiation

(7)


150r T.B.
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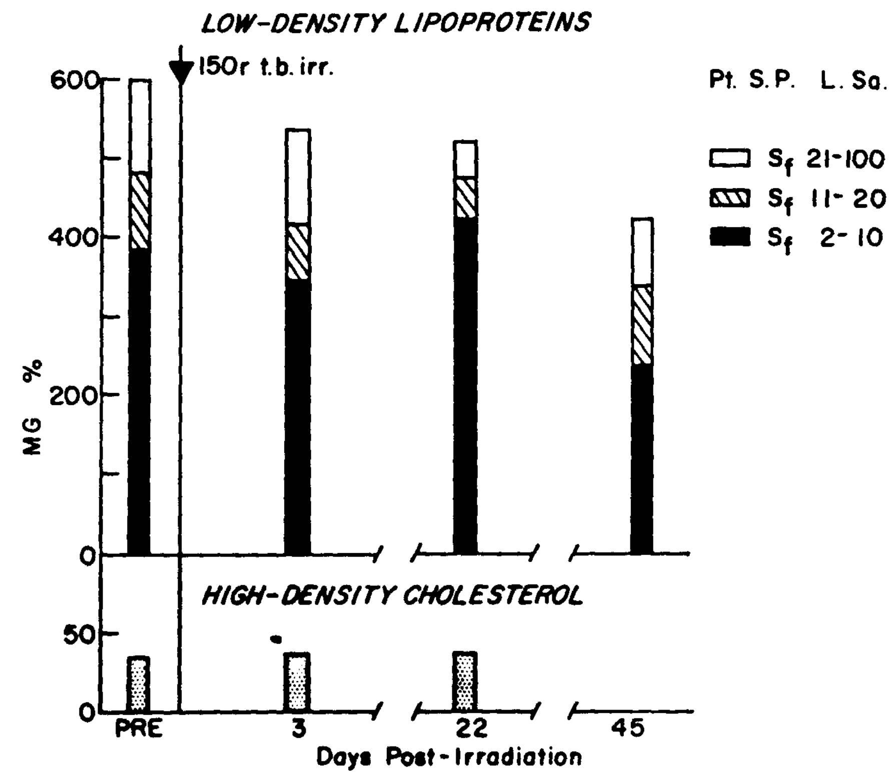
Sf 11-20
Sf 2-10
α Cholesterol
Pt. W.H. Ca Lip
150r in air to
midplane
Low Density Lipoproteins mg%
600
500
400
300
200
100
0
Cholesterol α mg%
50
25
0
2
4
0
1
2
3
4
5
Days Post-Irradiation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Sf 21-100
Sf 11-20
Sf 2-10
MG %
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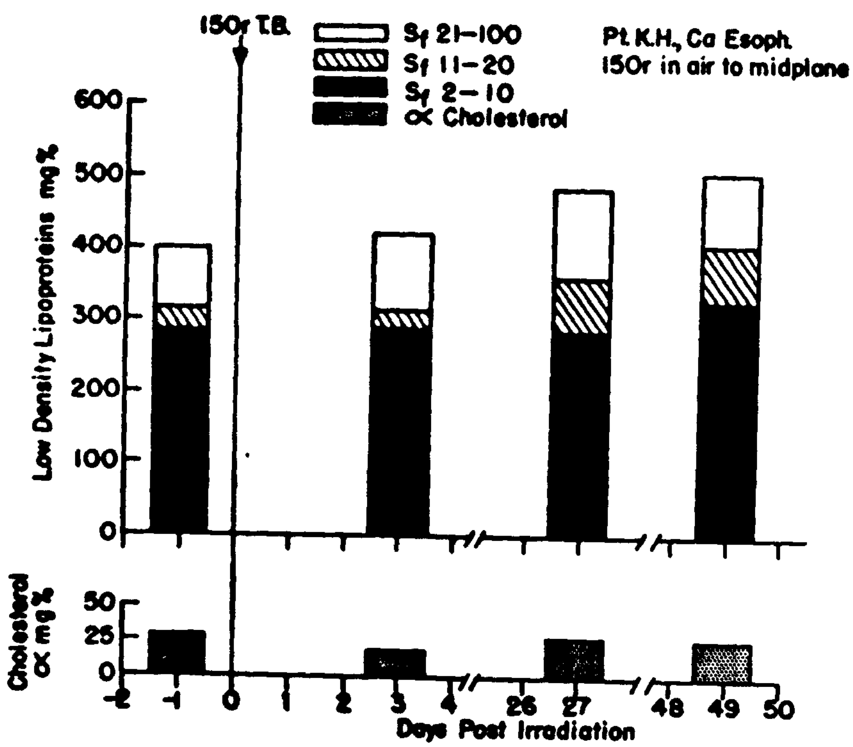
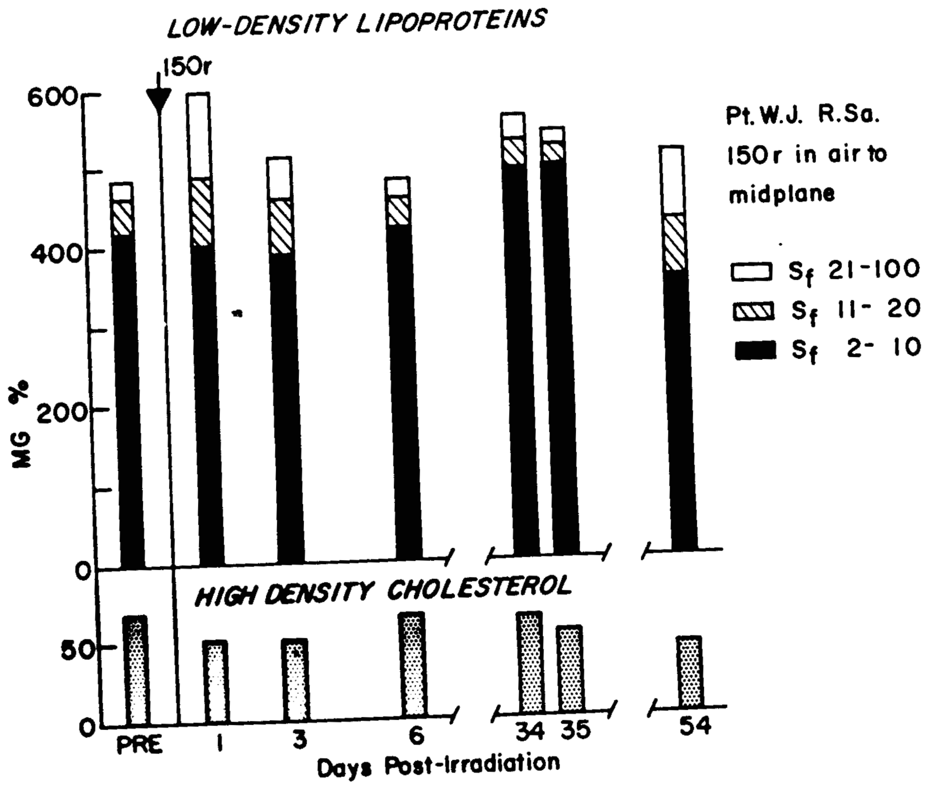
400
200
0
HIGH-DENSITY CHOLESTEROL
50
0
PRE
3
22
45
Days Post-Irradiation

(9)


150r T.B.
Sf 21-100
Sf 11-20
Sf 2-10
α Cholesterol
Pt. K.H., Ca Esoph.
150r in air to midplane
Low Density Lipoproteins mg%
600
500
400
300
200
100
0
Cholesterol α mg%
50
25
0
-2
-1
0
1
2
3
4
26
27
48
49
50
Days Post Irradiation

(10)


LOW-DENSITY LIPOPROTEINS
150r
600
400
200
0
MG %
Pt. W.J. R.Sa.
150r in air to
midplane
Sf 21-100
Sf 11- 20
Sf 2- 10
HIGH DENSITY CHOLESTEROL
50
0
PRE
1
3
6
34
35
54
Days Post-Irradiation