The Distribution of Doses of Radioactive Phosphorus in Leukemic Patients*†

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The therapeutic value of radioactive phosphorus (P³²/), first utilized by Lawrence for the treatment of leukemia, is being rapidly established (3, 5, 7, 8, 12). In general it may be said that this radioactive isotope affords a reasonably efficacious means of radiation of leukemic cells without producing radiation sickness.

While numerous tracer studies (6) have been carried out with the aid of radioactive phosphorus, the possibility must be considered that there may be some alterations in the absorption and retention of the isotope, when given in larger amounts, due to the biological effect of the β radiation such as, for instance, a change in cell permeability. The alteration of cell permeability by radiation has been clearly established. Undoubtedly there are considerable variations in the amount of radioactive material absorbed in the different tissues because of variations in the amount of blood contained, in the degree of leukemic infiltration, in the extent of necrosis of leukemic cells, and in the extent of necrosis of normal but highly radiosensitive cells, entirely apart from the selective absorption of the tissue elements themselves.

Radioactive phosphorus has been administered as Na₂HPO₄, usually in doses of 1 to 3 mcg, given in approximately 300 cc. of 5 per cent glucose and 0.85 per cent saline intravenously. The amounts of total phosphorus (P³¹ + P³²) administered with each dose vary according to the specific activity of the lot used; the range is from 2 to 20 mgm. of phosphorus. The half life of P³² is 14.3 days. It disintegrates to sulfur, giving off β radiation that is capable of penetrating 2 to 4 mm. of tissue. As a rough comparison with more familiar types of radiation, 1 mcg. retained in 1 gm. of tissue for 24 hours delivers 43 roentgen equivalents to that tissue (10).

Owing to the relatively low penetrating power of these β radiations, the effect of radiation on any given tissue depends largely upon the amount of radioactive phosphorus absorbed and retained by that tissue. Therefore it is important to know the amounts present in various tissues and fluids of the body at various times after administration of this radioactive material.

This study is based on autopsies in 10 leukemic patients performed 1 to 35 days after the last dose of radioactive phosphorus was administered. In most of the autopsies reported here the radioactive phosphorus had a high specific activity—from 0.5 to 0.14 mcg. per mgm. of phosphorus. Measurements of radioactivity were carried out with the aid of a Lauritsen type electroscope or a modified Geiger counter, accurate within 10 per cent to as low as 0.001 mcg. All measurements were calculated back to the date of the last injection given.

The material was obtained at autopsy by removing aliquot samples of tissue ranging from one entire organ in the case of the adrenals to 20 or 30 gm. in the case of the liver. Most of these samples were dried and ashed at 400° C. before measurement. Wetashing was carried out on some samples and no significant variation from the dry ash method was encountered.

For convenience in discussing the data the cases have been divided into three groups: acute leukemia in adults (3 cases), acute leukemia in children (5 cases), and chronic leukemia in adults (2 cases). The deposition of P³² was virtually the same in all three.

Table I presents the essential data. The results are expressed in microcuries per gram of tissue and per cubic centimeter of body fluids. Our results are of much the same order of magnitude as those of Lawrence (8) and Erfl (1).

Evidence that the amount of tumor may be a dominant factor in the distribution of the radioactive material is seen in our case 40 (Table I), where involved liver and lymph node gave comparable results, 0.112 and 0.112 respectively; in case 44 (Table I), where tumor tissue involving spleen, liver, and
| Case No. | Days * | Days Ac. | Total dose, n. | Heart | Lung | Spleen | Thymus | Liver | Intestine | Adrenal | Kidney | Uterus | Lymph nodes | Aorta | Thymus | Muscles | Fat | Cartilage | Bone | Cerebral home | Brain | Marrow | Brain | Blood | Urine | Peritoneal fluid | Spinal fluid | Ribs | Pleural fluid |
|---------|--------|----------|----------------|-------|------|--------|--------|-------|----------|--------|--------|-------|-------------|-------|--------|---------|----|------------|------|---------|-------|-------|------|----------------|-------------|-------|--------------|
| 18      | 5      | 22.6     | 2,965          | .0465 | .107 | .0846  | .0317  | .0408 | .0427    |        |        |       |             |       |        |         |    |            |      |          |       |       |       |                |             |       |              |
| 40      | 13     | 20.4     | 4,710          | .079  | .074 | .053   | .077   | .112  | .059    | .0845  | .0322  | .112  | .0338       | .0156  | .0384  | .0079   |    | .0648†       | .96† | .0125   | .0278 | .052  |       |                |             |       |              |
| 51      | 15     | 26.8     | 6,272          | .051  | .076 | .076   | .059   | .097  | .065    | .073   | .039   | .021  | .014        | .012   | .027   | .009    | .010| .0034       | .079 | .0034   | .0004 |       |       |                |             |       |              |
| 49      | 12     | 30.0     | 3,880          | .03   | .033 | .058   | .04    | .058  | .03     | .04    | .02    | .009 | .007†       | .027   | .011   | .008**  | .008| .0012       | .005 | .004    | .008† |       |       |                |             |       |              |
| 107     | 40.0   | 79.7     | 69             | 12.2  | .125 | .0785  | .1     | .148  | .057    | .020   | .086   | .069  | .037         | .06    | .0211  | .0735   |    |             |      |          |       |       |       |                |             |       |              |
| 82      | 20.0   | 83.2     | 50             | 13.2  | .076 | .0266  | .0575  | .0136 | .0396   | .0049  | .0975  | .0324 | .053          | .0058  | .0096  | .0015   | .0605| .0004       | .004 | .0004   | .00455 | .0525|       |                |             |       |              |
| 24      | 14.0   | 32.2     | 25             | 13.1  | .028 | .015   | .031   | .031  | .043    | .076   |        |       |             |        |        |         |    |             |      |          |       |       |       |                |             |       |              |
| 36      | 28.4   | 33.8     | 38             | 13.2  | .00455| .053   | .0705  | .0156 | .0382   | .0493  | .0124  | .0256 | .214†        | .373†  | .00046 | .0224   | .00455| .0525       |       |          |       |       |       |                |             |       | 142‡        |
| 22      | 14.0   | 15.1     | 22             | 13.9  | .027 | .0528  | .0229  | .0365 | .0056   | .0382  | .0493  | .0124 | .0256         | .214†  | .00046 | .0224   | .00455| .0525       |       |          |       |       |       |                |             |       | 142‡        |
| 23      | 15.1   | 18.9     | 35             | 35.7  | .00465| .0313  | .0229  | .0365 | .0056   | .0382  | .0493  | .0124 | .0256         | .214†  | .00046 | .0224   | .00455| .0525       |       |          |       |       |       |                |             |       | 142‡        |
| 99      | 33.6   | 2,250    | 38             | 38    | .0313 | .0386  | .0313  | .059  | .0492   | .0395  | .0389  | .0179 | .022          | .00856 | .0356† | .0678†  | .0116| .042         |       |          |       |       |       |                |             |       |              |

* Number of days each administration precedes death.  † Ribs.  ‡ Vertebra.  § Femur.  || Meninges.  ** Right heart.  †† Left heart.  ††† Leukocytes.
lymph nodes gave closely parallel readings, 0.122, 0.125, and 0.148 respectively; and in case 9 (Table I), spleen 0.059, liver 0.059, tumor from soft parts (intestinal nodule) 0.058, and tumor from bone marrow 0.068 mc. per gm. The time interval after administration of the last dose of radioactive material in these cases varied from 2 to 9 days.

As the time interval increased, the bone contained a relatively larger amount of radioactive phosphorus. Thus the ribs of case 23, 14 days after the administration of 901 mc., held over 10 times as much P\textsuperscript{32} as case 49 one day after the administration of 1,060 mc. In the short time most of our patients lived following the last dose even this was influenced by the degree of leukemic infiltration, as shown by case 23, where the amount of P\textsuperscript{32} retained in the tissues was highest in the rib involved in the leukemic process, less in a vertebra, which also was less involved, and least in the femur, which showed the smallest amount of leukemic infiltration. These readings were obtained 14 days after the last dose was given.

As evidence that the hepatic cells themselves as well as the leukemic cells present in the liver take up P\textsuperscript{32} actively, the amount present in the bile may be cited. Thus in cases 40 and 51 the amount per cubic centimeter of bile equals that per gram of spleen. However, in case 49 the bile contained relatively little. In this case there was other evidence of hepatic dysfunction.

Some tissues took up but little P\textsuperscript{32}, chiefly owing to the small amount of nuclear material and protoplasm in relation to total mass. Thus in case 40, fat showed one-fourteenth the concentration found in the liver and in case 51, one-eighth.

In these short term observations cortical bone did, however, show a fairly high concentration of P\textsuperscript{32}, as would be expected from its chemical composition.

Striking is the slight amount of radioactive material found in the brain in spite of the importance of phosphorus in its substance. This was uniformly lower than in any of the other tissues. This result may be expected in view of the low rate of metabolism of the brain. The amount in the spinal fluid was much lower than in the blood, owing to the absence of any number of cells in the spinal fluid.

Within a few hours after injection but little P\textsuperscript{32} remains in the blood plasma, and that circulating is practically all in the blood cells (2). Soon after injection of P\textsuperscript{32} the liver, spleen, lungs, kidneys, and bone contain the largest amounts of the material. These earlier results have been checked by a later series, as yet unpublished, which gives comparable results. Thus P\textsuperscript{32} administered to normal rodents (4, 9, 13) as well as to leukemic human subjects shows the same tendency to be deposited, at least at first, in some of those organs where leukemic infiltration is apt to occur. This localization, combined with the differential absorption by the rapidly growing leukemic cells (11), gives P\textsuperscript{32} a differential deposition clearly favorable to the selective irradiation of leukemic cells.

**SUMMARY**

The deposition of radioactive phosphorus, as determined in the tissues of 10 patients dead of leukemia, was greatest in those tissues that usually show a heavy infiltration of leukemic cells. The liver, spleen, kidneys, and bone marrow contained relatively large amounts. Slowly metabolizing tissues, as brain, fat, and cartilage, contained but little. The concentration in the bile was sometimes fairly high.

The distribution of P\textsuperscript{32} in human tissue is generally comparable with that obtained in rodents experimentally.

**REFERENCES**

GASTROINTESTINAL TRACT


The conception is presented that the gastric mucosa can act as an endocrine gland by means of hormones. There are pronounced differences in blood hormone content between the sexes, which may explain the sex discrepancy in gastric cancer.—H. G. W.


A discussion of operative technic.—H. G. W.


The prevalent assumption that prepyloric ulcers are more likely to be malignant than ulcers situated elsewhere in the stomach has been challenged in recent years. To obtain information that might help to solve the question, ulcerous prepyloric lesions observed roentgenologically and operated on at the Mayo Clinic during the period 1937 to 1941 inclusive were reviewed. All ulcerating carcinomas that had been diagnosed roentgenologically were excluded from consideration. After other exclusions made necessary by the roentgenologic approach, there remained 61 ulcerating carcinomas and 71 ulcers; of the latter, 63 were benign and 8 (11.3%) malignant. These figures are compatible, though not identical, with the generally accepted estimate that from 10 to 12% of all gastric ulcers prove to be malignant. This study thus supports the newer view that prepyloric ulcers are not more often carcinomatous than are gastric ulcers in other locations.—H. G. W.


Three cases of multiple adenomatosis of the colon are presented, in all of which malignancy had developed. One patient had a family history of bowel malignancy.—H. G. W.


Of the 30 cases of limitis plastica observed, 26 involved the stomach, 3 the large intestine, and 1 the gall bladder. The time interval between the onset of symptoms and death was much shorter than with other types of cancer and the survival time after operation was very brief. Metastasis to the liver was found only 3 times, but among 6 females the ovaries were involved 3 times. It is very questionable whether limitis plastica, in the sense of a purely inflammatory, nonmalignant lesion, exists.—H. G. W.


A report of a carcinoid tumor growing from the stump of the appendix into the cecum with metastases to the regional lymph nodes. This is the 77th reported case of malignant carcinoid tumor.—H. G. W.


The 3 cases here reported are the only ones to be found in the literature.—H. G. W.


Case of a 25 year old male was remarkable for the total absence of Bence-Jones proteinuria and for an absorption of bone so extensive that the body of the patient seemed like a flattened, collapsed, fluctuant mass.—H. G. W.


A report of the survival for 13 years of a patient with an osteogenic sarcoma of the femur and numerous pulmonary metastases.—H. G. W.

BONE AND BONE MARROW

BAILEY, W., and KISKADDEN, W. S. [Los Angeles, Calif.] TREATMENT OF HEMANGIOMATA, WITH SPECIAL REFERENCE TO UNSATISFACTORY RESULTS. Radiology, 39:582-581. 1942.

Success in the treatment of hemangiomas often depends on selection of the appropriate form of therapy. Radiation usually gives poor results in capillary hemangiomas or "port wine stain" since doses large enough to produce permanent skin injury are necessary to destroy the mature capillary endothelium. The hypertrophic endothelial hemangioma or "strawberry mark" is made up of masses of proliferating endothelium and generally responds well to radiation. Surgical excision is usually the treatment of choice in cavernous hemangioma, although radiation may sometimes be used. Sclerosing solutions, carbon dioxide snow, and electrocoagulation have been successfully used but have several disadvantages. The technic of surface and interstitial radium and radon application is discussed in detail.—C. E. D.

Correction

The author of the paper entitled "The Distribution of Doses of Radioactive Phosphorus in Leukemic Patients," Cancer Research, 3:334-336. 1943, wishes it said that mc. in lines 5, 11, and 12 on page 336 should have been μc.
The Distribution of Doses of Radioactive Phosphorus in Leukemic Patients

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