TISSUE DISTRIBUTION AND TUMOUR LOCALIZATION OF 99m-TECHNETIUM-LABELLED LIPOSOMES IN CANCER PATIENTS

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Summary.—The possible use of liposomes (phospholipid vesicles) to direct cytotoxic drugs to tumours has led us to investigate the tissue localization of i.v. injected 99m-Tc-labelled liposomes in cancer patients. Twenty mg or 300 mg doses of liposomal lipid (7:2:1 molar ratio of phosphatidylcholine:cholesterol:phosphatidic acid) were used in a study of 13 patients with advanced cancer and one with polycythaemia rubra vera (PRV). In all cases except the patient with PRV the major site of uptake of the label was the liver and spleen. In the patient PRV the liver uptake was greatly reduced and the major site of uptake was found in regions corresponding to marrow. With the exception of one patient with a primary hepatoma, there was no significant tumour uptake of the label.

LIPOSOMES are small phospholipid vesicles (25 nm–5 μm diameter) consisting of one or more sealed concentric lipid bilayers separated by aqueous compartments (Bangham et al., 1965). Their structure offers a biodegradable vehicle for the carriage of cytotoxic agents trapped either in their aqueous or lipid layers (Juliano & Stamp, 1978; Papahadjopoulos, 1978). Animal experiments suggest that liposomally entrapped antineoplastic drugs may prove useful in cancer chemotherapy, and may offer advantages over more conventional methods of chemotherapy (Rutman et al., 1977; Kobayashi et al., 1977; Kosloski et al., 1978). However, there appears to be some doubt as to the exact mechanism by which liposomally entrapped drugs may be more effective than non-entrapped drugs. Liposomally entrapped drugs may exert their effects either by a prolongation of the plasma half-life of the cytotoxic drug (Colley & Ryman, 1975; Juliano & Stamp, 1978) or liposomes may impart an increased tumour affinity to the entrapped drug by the liposomes actively localizing in the tumour tissues (Dapergolas et al., 1976). However, liposomes injected i.v. are mainly taken up by the cells of the liver and spleen (Gregoriadis & Ryman, 1972). Specific accumulation of liposomes in tumours, and particularly in tumour cells, would be of considerable advantage in improving the selectivity of anti-cancer drugs. Such a possibility seems feasible in view of reports that some tumour cells have a high endocytic activity (Busch et al., 1961; Ghose et al., 1962; Easty et al., 1964; Mego & McQueen, 1965; Trouet et al., 1972) which may enhance uptake of liposomes. Previous studies with animal models have shown that tumour localization of liposome markers is possible by a careful selection of the size and membrane properties of the liposome (Dapergolas et al., 1976; Richardson et al., 1977, 1978b). There have also been two reports on the possible tumour localization of liposomal markers in patients (Gregoriadis

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et al., 1974; Segal et al., 1976). In one of these (Gregoriadis et al., 1974) localization of the label was seen in tumour tissue. The other report (Segal et al., 1976) was inconclusive. In the first of these, 131I-labelled serum albumin was used as a marker for the liposomes and in the second 111In-labelled bleomycin was used as a liposomal marker. Recently Richardson et al. (1978a) have shown that liposomes can be labelled with 99mTc, a versatile nuclide extensively used in nuclear medicine, with chemical and physical properties ideally suited for labelling and radionuclide imaging (Subramanian et al., 1975). Animal studies using such labelled liposomes have shown that tumour localization can be achieved, and that this can be visualized with a gamma camera (Richardson et al., 1978a).

Pharmaceutical preparations of liposomes consisting of neutral lipids have been prepared, and the distribution of an i.v. injected 99mTc-labelled preparation has been reported in a patient with a primary hepatoma, but without any significant tumour localization (Richardson et al., 1978b).

The toxicity of liposomes of several lipid compositions has been investigated in mice (Adams et al., 1977). Other investigators have also used liposomes containing a 7:2:1 molar ratio of egg phosphatidylcholine, cholesterol and phosphatidic acid without any observable toxic effects in rats (Gregoriadis, 1976) or man (Gregoriadis et al., 1974; Tyrrell et al., 1976; Belchetz et al., 1977). However, some lipid compositions used in making liposomes have had toxic side effects (Bruni et al., 1976; Adams et al., 1977; Steger & Desnick, 1977). Animal tumour studies have shown that very small negatively charged liposomes appear to concentrate well in tumour tissue (Richardson et al., 1978a). We now report the results obtained from 14 patients injected with 99mTc-labelled negatively charged liposomes, composed of a 7:2:1 molar ratio of phosphatidylcholine:cholesterol:phosphatidic acid.

**MATERIALS AND METHODS**

*Preparation of liposomes.*—Batches of negatively charged (anionic) liposomes, composed of a 7:2:1 molar ratio of egg phosphatidylcholine (lecithin):cholesterol:phosphatidic acid, were prepared in a sterile, pyrogen-free form by the method previously described by Richardson et al. (1978b). Two different dose levels of liposomes were used in these studies; either of 20 or 300 mg of lipid per patient. Liposomes were prepared as required and stored at 4°C for periods of up to 6 weeks under an atmosphere of N2. Before labelling with technetium, each dose of liposomes was further sonicated, using a Megason Ultrasonic bath, for between 4 and 5 h to break up any aggregates.

*Preparation of 99mTc-labelled liposomes.*—Two methods of labelling the liposomes with 99mTc were used. In the earlier studies using 20mg doses of lipid, a stannous chloride method was used as follows. About 670 mg of Analar SnCl2.2H2O was dissolved in 100 ml of O2-free water (suitable for injection) prepared by passing O2-free N2 through a sterile 0.22μm Millipore filter, and then bubbling this for at least 10 min before the addition of the stannous chloride. The bubbling was continued during the course of the rest of the procedure. After the stannous chloride was dissolved the solution was sterilized by passing through a sterile 0.22μm Millipore filter and 0.5ml aliquots were dispensed into evacuated multidose vials, which were stored at 4°C and used within 3 weeks. The whole of the preparative procedure was performed in a laminar-flow cabinet, and all batches were tested for pyrogenicity and sterility, as previously described (Richardson et al., 1978a). Liposomes were labelled simply by adding 1 ml of liposomes (20 mg lipid) in 0.9% saline and 1 ml (15–20 mCi) of sodium per-technetate simultaneously to the 0.5 ml of SnCl2 solution and mixing well. The mixture was allowed to stand for 15 min before use. A small portion of each preparation of liposomes used for the patient studies was tested for sterility. In later patient studies using 300mg doses of lipid, the method of preparing the SnCl2 was modified to increase its shelf-life. After dispensing the 0.5ml aliquots of SnCl2, prepared as above, the samples were freeze-dried and then further sterilized by gamma radiation (5 M rad over a period of 26 h). 3 ml of liposomes (300 mg lipid) in
0.9% saline and 0.5 ml (15–20 mCi) of sodium pertechnetate were injected simultaneously through the rubber stopper of the vial, mixed with the solid stannous chloride and left to stand for at least 15 min before use.

Selection and injection of patients in the study.—All patients had histologically confirmed tumours as listed in Table I. Informed consent from all patients was obtained before the liposomes scans were performed.

Potassium perchlorate (400 mg) was given orally to Patients 1a, 2 and 4 before liposome administration to ensure thyroid protection in the unlikely event of the technetium detaching from the liposomes. Liposomes labelled with 15–20 mCi of technetium were injected i.v., usually into a vein in the arm, but in one case (Patient 6) the liposomes were injected as a bolus through an i.v. drip into a vein in the leg. Before injection all doses of liposomes were compared with a sodium pertechnetate (99mTcO4-) standard to determine the injected dose and relative activity of blood and urine samples taken after injection.

Blood clearance of the 99mTc label.—The blood clearance of the 99mTc label was measured by taking blood samples at intervals after injection of the 99mTc-labelled liposomes (see Table II). Blood samples were collected into heparinized containers and 1 ml samples of whole blood were used to determine radioactivity, and compared to the standard solution of sodium pertechnetate (99mTcO4-) used to determine the injected dose.

Dynamic study of liver uptake of 99mTc label.—Dynamic studies were made of the liver uptake of the 99mTc label in some of the patients. Where this was done before injection, the patients were seated or placed supine with the gamma camera (Nuclear Enterprise wide field Mark V) centred over the posterior aspect of the lower thoracic and upper lumbar region. The area visualized included most of the liver, spleen, kidneys, spine, stomach, lungs and heart. Liposomes were injected and the change in distribution of radioactivity was recorded for 30 min with a Varian data-processing system linked to the gamma camera. The time–radioactivity curve over the organs of interest was computed from the data recorded (see Fig. 1).

Tissue distribution of the 99mTc label.—At ~5 and 24 h after injection, whole-body images showing the tissue distribution of radioactivity were made of the patients with an Elscint double-headed whole-body scanner. The distribution of the 99mTc label was recorded using a Varian computerized data-processing unit. The images of the radioactive distribution were then displayed on a television screen and a photographic record made. Some of these pictures are shown in Figs. 2 and 3.

Excretion of the 99mTc label in the urine.—Samples of urine were collected from two patients (2 and 3) in 6-hourly periods over the 24 h after injection, and the volume and 99mTc content determined for comparison samples with the 99mTc standard. In this way the percentage of the injected dose excreted was determined for each of the samples (see Table III).

RESULTS

Table I gives details of the 14 patients selected for this study. Ten subjects had solid tumours with widespread metastases, 2 had primary hepatomas with disease confined to the liver and 2 had haematological malignancies. In the case of Patient 1 (see Table I) two studies were made, once with a 20 mg dose of liposomes (Study 1a) and 9 months later with a 300 mg dose of liposomes (Study 1b). Patients 2–9 each received a 20 mg dose of liposomes, whilst Patients 10–14 each received a 300 mg dose (see Table II). A description of the histologically confirmed tumour, the primary site, sites of secondary metastases where known, and the interval between therapy and scanning are also given in Table I. Only 3 of the patients (6, 9 and 10) had received no chemotherapy before the study, and in 5 of the remaining 12 studies (1a, 3, 4, 7 and 13) no chemotherapy had been given for over 1 month. Details of the major drug regimes used for each patient are given in Table I.

Table II shows the blood clearance of the 99mTc label as determined in 10 of the patients. The initial blood sample taken at ~5–10 min after injection was called the 100% value, and all other samples were compared with this. Few blood samples were taken, but it appears that there is an initial rapid clearance with a half-life of
TABLE I.—Details of patients studied

| Patient No. | Sex | Tumour or disease       | Known sites of disease          | Drug therapy       | Interval between therapy and scanning |
|-------------|-----|-------------------------|---------------------------------|--------------------|---------------------------------------|
| 1.          | ♂   | Hepatoma                | Liver                           | (a) Adria          | 4 months                              |
|             |     | (b)                     |                                 | (b) VP Adria       | 1 day                                 |
| 2.          | ♂   | Choriocarcinoma         | Uterus, both lungs, brain       | 7 Drug comb        | 3 days                                |
| 3.          | ♂   | Hepatoma                | Liver                           | CB 10252           | 35 days                               |
| 4.          | ♂   | Polycythaemia rubra vera| Spleen liver, marrow            | Busulphan          | 18 months                             |
| 5.          | ♂   | Hypernephroma           | Kidney (L), both lungs          | Cis plat           | 13 days                               |
| 6.          | ♂   | Acute myeloblastic      | Marrow                          | None               | —                                     |
|             |     | leukaemia               |                                 |                    |                                       |
| 7.          | ♂   | Teratoma of testis      | Testis (R) removed, lung (R)    | VCR/MTX/Bleo       | 28 days                               |
| 8.          | ♂   | Choriocarcinoma         | Uterus, liver, both lungs       | VCR/MTX/Cis plat   | 2 days                                |
| 9.          | ♂   | Adenocarcinoma of breast| Breast (R), axillary lymph       | None               | —                                     |
|             |     |                         | nodes (R)                       |                    |                                       |
| 10.         | ♂   | Carcinoma of bronchus   | Lung (L), brain (R)             | None               | —                                     |
| 11.         | ♂   | Haemangiopericytoma     | Thigh (L), both lungs           | VLBE/Chlor/Adria   | 21 days                               |
| 12.         | ♂   | Kaposi’s sarcoma        | Leg (R) amputated, lung (L),    | Razoxin            | 26 days                               |
|             |     |                         | liver, inguinal lymph           | (ICRF 159)         |                                       |
|             |     |                         | nodes (R)                       |                    |                                       |
| 13.         | ♂   | Choriocarcinoma         | Uterus, both lungs, pelvis      | 7 Drug comb        | 28 days                               |
| 14.         | ♂   | Choriocarcinoma         | Uterus, kidney, both lungs      | VP 16–213          | 1 day                                 |

Abbreviations:
Adria = Adriamycin. Bleo = Bleomycin. CB 10252 = Alkylation agent from Chester Beatty Research Institute, activated by tissue azoreductase. Chlor = Chlorambucil. Cis plat = Cis diammine dichloroplatinum. 7 Drug comb = Hydroxyurea, vincristine, methotrexate, actinomycin D, cyclophosphamide, adriamycin and melphalan. MTX = Methotrexate. VCR = Vincristine. VLBE = Vinblastine. VP 16–213 = Semi-synthetic podophyllotoxin epoxide.

TABLE II.—Dose levels and blood clearance of 99mTc label associated with anionic liposomes

| Patient (see Table I) | Dose of lipid given (mg) | Percent of initial blood sample (Time min) | (Time h) |
|------------------------|--------------------------|------------------------------------------|-----------|
| 1a                     | 20                       | ND                                       | ND ND ND ND |
| 1b                     | 300                      | ND                                       | ND ND ND ND |
| 2                      | 20                       | ND                                       | 100 (32) 74 (3) 24 (23) |
| 3                      | 20                       | 100 (4)                                 | ND ND ND ND |
| 4                      | 20                       | 100 (10)                                | 86 (35) ND 10 (24) |
| 5                      | 20                       | 100 (7)                                 | 86 (30) ND 9 (24) |
| 6                      | 20                       | 100 (5)                                 | 90 (29) ND 12 (24) |
| 7                      | 20                       | 100 (8)                                 | 74 (26) ND 0-2 (24) |
| 8                      | 20                       | 100 (14)                                | 82 (50) ND 18 (20) |
| 9                      | 300                      | 100 (7)                                 | 72 (30) 28 (5) 10 (24) |
| 10                     | 300                      | 100 (9)                                 | 72 (25) 39 (5) 10 (24) |
| 11                     | 300                      | 100 (9)                                 | 82 (55) 27 (5-5) 2-5 (24) |
| 12                     | 300                      | ND                                      | ND ND ND ND |
| 13                     | 300                      | ND                                      | ND ND ND ND |
| 14                     | 300                      | ND                                      | ND ND ND ND |

ND—not done.

~3 h, followed by a slower clearance with a half-life of ~8–12 h. Patients given the higher dose of lipid had a slightly more rapid initial blood clearance.

Table III shows the urinary excretion of the technetium label over the first 18 h (Patient 3) and 24 h (Patient 2). In both cases ~25–30% of the injected label was excreted in the urine over this period.

Fig. 1 is the computer-drawn time-activity curves over the regions of the liver (L), heart (H) and other tissues which were used as a background (B) during the course of the first 30 min after injection of
Table III.—Excretion of the $^{99m}$Tc label in the urine

| Patient | Time during which urine collected (h) | % dose injected in urine exerted | % dose injected in urine exerted |
|---------|--------------------------------------|---------------------------------|---------------------------------|
| 2       | 0-6                                  | 8                               |                                 |
|         | 6-12                                 | 13                              |                                 |
|         | 12-24                                | 9                               |                                 |
| 3       | 0-6                                  | 10                              |                                 |
|         | 6-12                                 | 6                               |                                 |
|         | 12-18                                | 8                               |                                 |

Fig. 1.—Variations in radioactivity over regions of the H (heart), L (liver) and B (background tissues) as obtained from computerized data recorded over the first 25 min after i.v. injection of 300 mg of $^{99m}$Tc-labelled liposomes into Patient 14 (choriocarcinoma).

The liposomes into Patient 14. It shows the uptake of the liposomal label and the blood clearance of $^{99m}$Tc, represented by the values recorded over the heart region during this period. The liver (L) localizes the activity rapidly over the first 5 min. This is paralleled by a rapid fall in activity over the region of the heart (H). The liver continues to take up activity rapidly over a period of 15 min, when the uptake becomes slower. No accumulation of activity was observed in any of the other organs, including the kidneys and stomach.

Fig. 2 shows the whole-body scans of Patient 2 (see Table I) at (a) $4\frac{1}{2}$ h and (b) 24 h after injection, and shows the tissue distribution of the technetium label. The first scan shows high activity in the liver and also in the heart, lungs and marrow. The latter scan shows the effects of blood clearance and tissue deposition of the label at 24 h. The activity in the lungs and heart had diminished (the average fall in activity between these times for the patients studied was $\sim 75\%$). The activity appears to have accumulated greatly in the liver and remains to some extent in the marrow. There appears to be no significant accumulation of radioactivity in the primary tumour (choriocarcinoma) or in secondary metastases (lungs and brain) at either time scanned.

Whole-body scans showing the organ distribution of the $^{99m}$Tc label in 3 of the patients at 24 h are shown in Fig. 3. In all of the patients, excluding Patient 3 who had a large hepatoma and Patient 4 with polycythaemia, the normal liver tissue was the main site of uptake of the label. This was true for patients given both high and low doses of lipids. In the hepatoma patient (Patient 3) the main site of uptake was the grossly enlarged spleen; some of the label was also seen in the salivary glands (see Fig. 3a). Liver and spleen uptake were greatly reduced in Patient 4 with polycythaemia and the majority of radioactivity remaining in this patient was found in the marrow and kidney (Fig. 3b).

Patient 1a (Fig. 3c) shows technetium localization in the normal liver tissue and also in the area of the tumour. However, using an alternative scanning agent (technetium stannous colloid) shortly before the liposome study, there was no visible tumour localization (Fig. 3d). An attempt
to repeat the observed apparent liposome localization in the tumour at a later date using a 300 mg dose of lipid shortly after a course of chemotherapy was negative. In the case of Patient 1a (Fig. 3c) there appears to be axillary lymph node localization of a small portion of the liposomes which had inadvertently been extravasated during administration. With the possible exception of Patient 1a (Fig. 3c) who had a primary hepatoma, there was no evidence of any significant tumour localization of the radioactivity after injection of $^{99m}$Tc-labelled liposomes.

**DISCUSSION**

There have been two studies, using animal tumour models, showing tumour localization of labelled liposomes (Neerunjun et al., 1977; Richardson et al., 1977) and one study in which no tumour localization was observed (Anghileri et al., 1976). Patient studies have also been reported (Gregoriadis et al., 1974; Segal et al., 1976) but in only one of these (Gregoriadis et al., 1974) has there been a significant tumour accumulation of the liposome label, in a single patient with cancer. From these data and the present relatively negative results it would appear that there are differences between the rat tumour models and the human tumours studied, and this could be due to factors related to the tumours themselves or to differences in the physical or behavioural properties of the liposomes.
The endocytic activity of certain tumours could be related to their growth rates, the rapidly proliferating tumours having a higher endocytic activity. Most human tumours studied were more slowly growing tumours than the transplantable animal tumours studied. There is also the possibility of large differences in surface properties between animal and human tumour cells. Such differences may manifest themselves in variations in liposome receptor regions on the surface of tumour cells. Cytotoxic chemotherapy may also damage endocytosis, and there have been reports that cyclophosphamide and other cytotoxic drugs suppress phagocytosis (Sharbaugh & Grogan, 1969; Magarey & Baum, 1970; Lokich et al., 1974). Drug treatment and length of time between chemotherapy and liposome scans in our studies were recorded (Table I). However, no relationship between the behaviour of the $^{99m}$Tc label and the type of drug therapy given or the interval between treatment and scanning was found.

The rate of metabolism of the liposomes may be different in the Walker 256 rat tumour used in the animal model described by Richardson et al. (1977, 1978a) and the human tumours. Lack of accumulation of liposomes in the human studies could conceivably be due to a rapid turnover of the liposome components, releasing the $^{99m}$Tc label from the tumour cells.

The possibility that differences in the physical properties of the liposomes used for animal and patient studies, due to the slight differences in preparation and storage of the patient doses of liposomes, led to changes such as fusion or deterioration of the lipid components was considered. However, injection of 6 Walker tumour-bearing rats with liposomes prepared for Patient 1a (Table I) showed that this was probably not the case, and the previously observed tumour localization of the label was found to be unchanged.

Liposomes are known to interact and attach to plasma proteins, $\alpha_1$-macroglobulins in human plasma and $\alpha_2$-
macroglobulins from rat plasma (Black & Gregoriadis, 1977). It is also known that plasma proteins can modify liposome properties (Black & Gregoriadis, 1977; Tyrrell et al., 1977). These variations in interactions with plasma proteins could explain why liposomes are not taken up by tumours in man, but are in rats.

The development of the technetium-labelling technique reported in this paper has allowed us to follow the tissue distribution of liposomes using neither biopsy nor necropsy, and to determine whether tumour localization has taken place. It may prove useful in evaluating whether or not liposomes can be modified in such a way as to make them more tumour-specific in man. Because $^{99m}$Tc has such a short half-life, several scans could be made safely in a single patient with different liposome preparations. The radiation hazard to the patient would be low.

The studies reported in this paper indicate that the distribution of $^{99m}$Tc-labelled liposomes in normal tissues of man and rats is similar. This included blood clearance, liver accumulation and excretion of the $^{99m}$Tc label (Richardson et al., 1977). However, in man the similarity excludes tumour localization, except perhaps in the one case of Patient 1a with a primary hepatoma. It may be noted that this was not found to be reproducible (Study 1b) using a larger dose of liposomes. However, the second of these studies was made the day following the end of a course of cytotoxic chemotherapy and this possibly influenced the results.

In our rat study (Richardson et al., 1977, 1978b) we reported that many factors influenced the tumour localization of the $^{99m}$Tc label. These included lipid composition, liposome charge, size and lipid fluidity. Further studies in cancer patients are required to examine the importance of each of these factors, as well as extending the range of tumours studied.

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