MEASUREMENTS OF RADIATION DOSES IN DIAGNOSTIC APPLICATIONS OF TC-99m

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1.INTRODUCTION.

The radiation burden induced by incorporation of radioactive substances was hitherto determined mainly by calculation /1/. Such an approach is based on certain assumptions regarding geometrical and kinetic data of the organs under investigation. In particular a simplified approximation for the size and shape of the organs /2/ and their relative positions must be adopted. Furthermore a conception must be formed for the kinetics of the radionuclide or the labeled compound, i.e. distribution and localisation, metabolic turnover and excretion. It is evident that these simplifying and generalizing assumptions may cause gross errors in the evaluated dose.
Thus it is difficult to judge on the influence of geometrical variations particularly in children /4/ since dose is calculated on the basis of a "standard man". With respect to kinetic parameters normal and pathological changes of metabolism and excretion can produce large deviations in dose from the estimate /5/. As it seems desirable to limit the number of assumptions in the determination of radiation exposure we tried to devise a method for an individual measurement. We used TLD as dosimeters for their small size , high sensitivity, mechanical stability and tissue equivalency. Technetium-99m was chosen as radionuclide for this study because of its numerous diagnostic applications and a simple decay scheme.

2.METHODS.

The dosimeters were lithium fluoride (TLD-100, Harshaw) chips (1/4" x 1/4" x x 0,035") and rods (1 mm ϕ x 6 mm).They were calibrated in a standardized geometry with Tc-99m the activity of which was determined in a dose-calibrator to ± 5%. A Remcal-Nuclear phantom from Alderson was taken for standardization measurements. Dose measurements were made on patients who were refered for scintigraphy of the liver (10 cases) and the thyroid (7 cases). Uptake and distribution of activity in the organs investigated were determined by a Pho-Gamma-III camera and a linear scanner.
The phantom was filled with water. Activity was administered to only one of the following volumes: liver, spleen, thyroid and trunk. A variable thickness of adipose tissue was simulated by several layers of vaseline. Surface dose was measured with chips while rods were inserted into the various volumes. Dosimeters at the surface were arranged in a grid around the body thus covering the organs of interest. This grid was composed of squares with 4 cm length each for liver and spleen, 2 cm for the thyroid resp. Besides dosimeters were located on the phantom and on patients in a variable distance from the organ under investigation to evaluate the contribution to dose from other parts of the body. The position of the dosimeters in relation to the organs was established by markers in the scintigram. Scintigraphy of liver and spleen was performed by application of 4-8 mCi Tc-99m-sulfur colloid, of the thyroid by 2-3 mCi Tc-99m pertechnetate. Dosimeters on the patient were positioned according to percussion findings, In some cases also the scans taken some minutes after application of the radioisotope were refered to. Dosimeters were fixed in the described pattern around liver and spleen or thyroid. Positions distant to the organs were the acromion for the trunk and the thigh. In thyroid studies additional dosimeters were placed over heart, stomach, kidneys and groins. Time period of measurement was 6-24 h.

3. CALCULATIONS AND RESULTS.

For the evaluation of the patient dose we correlated the values of dosimeters in the same position relative to the organ on the patients and on the phantom. In the calculation it was assumed that in scintigraphy of liver and spleen the organ dose is induced by three components: activity in the liver, activity in spleen and a nearly homogeneous distributed acitivity in the rest of the body. Results of measurement on the phantom indicated that accumulation in spleen and trunk is of little influence on dose values in positions close to the liver. Thus liver dose was determined first from these data. Next the dose values from the acromion area were corrected for contribution from liver activity and an estimate for the trunk dose was found in this way. Finally the splenic dose was calculated after correction for activity in liver and trunk.

With pertechnetate total body dose was evaluted from data of precordial region and acromion. Then the surface dose at the thyroid was corrected for trunk dose contribution and the thyroid dose due to accumulation in the thyroid itself could be determined. Total dose to the thyroid results from this plus the total body dose. Contributions from salivary glands and stomach need not be considered separately.

This regime yielded the following results: the liver dose in the phantom amounts to 0,21 rd/mCi, splenic dose to 1,0 rd/mCi and thyroid dose to 5,0 rd/mCi. These data do not take into account the decrease of the dose near the boundary of the organs and/or body surface. Since dimensions of the liver are larger than absorption half thickness for Tc-99m the resulting error for the total liver dose is small. Homogeneous distribution of acitivity in the trunk produces dose contributions in the different organs from 0,025 to 0,035 rd/mCi, average surface dose on the trunk was fount to be 0,010 rd/mCi. Dose contribution to the spleen by the liver activity was 0,015 rd/mCi, vice versa 0,010 rd/mCi.

(The volumes of the phantom organs were measured to:liver 1650 ml, spleen 130 ml, thyroid 23 ml and trunk (including head) 24 l.)

The data given in table 1 and 2show a greater decrease of surface doses with increasing thickness of vaseline for positions near the centre of the organ rather than near the contours according to a greater relative change in mean organ depth. Comparison of count rates obtained from the phantom and from patients with the gamma camera demonstrates imperfections in the anatomic imitation. In particular the liver is positioned rather superficially in the phantom. As a consequence all liver data were corrected for a covering layer of 2 cm tissue. Additional corrections were applied due to individual size and weight of the patient.

Table 1

	1	3	5	7	9	11	13	15	17	19
1	20	29	29	26	23	20	17	10	6	9
1(2)	18	28	26	23	20	20	16	-	-	-
1(4)	17	27	25	23	17	28	17	-	-	-
3	26	64	69	57	36	30	23	22	8	13
3(2)	26	51	57	49	29	27	21	-	-	-
3(4)	23	37	43	37	27	25	20	-	-	-
5	17	30	37	35	24	19	15	10	6	10
5(2)	16	29	35	33	23	20	23	-	-	-
5(4)	16	26	30	29	21	17	14	-	-	-

Integral dose at surface of phantom (mrd/mCi).Activity in the liver. Figures in brackets indicate the thickness of simulated fat in cm.

Table 2

	13	15	17	19	1	3
2	17	96	252	104	17	6
2(2)	-	78	174	87	-	-
2(4)	-	74	157	78	-	-
3	39	104	47o	218	18	10
3(2)	-	78	339	165	-	-
3(4)	-	70	224	148	-	-
4	17	61	139	131	10	7
4(2)	-	52	113	113	-	-
4(4)	-	48	96	87	-	-

Integral dose at surface of phantom (mrd/mCi)Activity in the spleen. For details see table 1.

The arrangement of dosimeter corresponds to a grid of squares (length 4cm). For the positions of dosimeter cf.fig.1. Each second row and column is given.

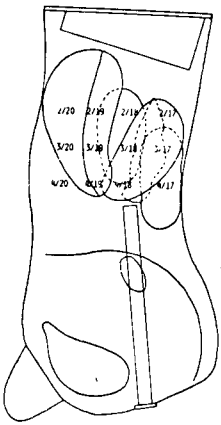

Table 3

Pat.	$\bar{D}_{liver}$ (rd/mCi) measured	calc.	$\bar{D}_{spleen}$ (rd/mCi) measured	calc.
1	0,14(0,12-0,16)	0,11	0,08(0,05-0,12)	0,08
2	0,18(0,15-0,22)	0,16	0,07(0,04-0,10)	0,09
3	0,15	0,13	-	-
4	0,17(0,14-0,20)	0,15	0,11(0,06-0,15)	0,11
5	0,16(0,14-0,18)	0,11	0,08(0,05-0,13)	0,08
6	0,27(0,16-0,35)	0,20	0,24(0,18-0,3o)	0,20
7	0,09(0,08-0,10)	0,09	0,04(0,02-0,06)	0,05
8	0,11(0,09-0,13)	0,14	-	-
9	0,15(0,13-0,18)	0,11	0,17(0,14-0,21)	0,20
1o	0,19(0,15-0,21)	0,15	0,15(0,10-0,19)	0,17

Average dose in rd/mCi (range in brackets) to liver and spleen after i.v. application of ^{99m}Tc-sulfur colloid. For details see text.

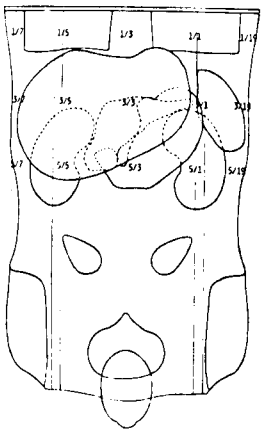

Table 4

Pat.	$\bar{D}_{th}$ (rd/mCi)	$\bar{D}_{tb}$ (rd/mCi)
1	0,15(0,11-0,18)	0,025
2	0,14(0,13-0,16)	0,020
2+	0,04(0,03-0,06)	0,022
3	0,15(0,13-0,16)	0,020
3+	0,07(0,06-0,09)	0,020
4	0,08(0,06-0,011)	0,023
5	0,11(0,09-0,13)	0,027
6	0,39(0,35-0,41)	0,020
7+	0,07(0,05-0,09)	0,025

Average dose (rd/mCi) to thyroid (th). and total body (t.b.) after i.v. application of ^{99m}Tc-pertechnetate.
(+) Patients whose thyroid was blocked.

Fig.1: Position of dosimeters on the phantom. Above: leftside view. Bottom: front view.

Table 3 and 4 give dose values for the patients which were calculated from their surface doses. Conventionally calculated dose values for liver and spleen were obtained by an estimate for accumulation in these organs via count rates from the gamma camera according to /1/. The data for specific absorption given by /2/ for a heterogeneous phantom were used.
For the patient no.3 in table 3 only a few dosimeters were evaluable because of positioning difficulties. Patient no.8 was splenectomized (no value for the spleen is given). In patient no.6 the extremely slim constitution may be responsible for the high dose which has not been corrected for. Calculated uptake in this case was found to be higher than 100% of applied activity. The increased scatter in the spleen data may be caused by the easy displacement of this organ within the abdominal cavity.
Table 4 gives dose values for the thyroid and total body after application of pertechnetate. For two patients (no.2 and 3) the measurements were repeated after blocking the thyroid. The radiation doses were significantly lower, similarly as in a patient who was examined under thyroid suppression only. Case 6 who exhibited a noticable high dose burden suffered from definite hyperthyroidism.

4. DISCUSSION.

The direct determination of radiation dose in patients after the administration of radioactive substances has to our knowledge been rarely accomplished. To some extent this might be caused by the fact that uncertainties introduced by geometrical factors are hardly reduced. In these preliminary studies we used a more realistic phantom instead of the "standard man" geometry. We have chosen simple diagnostic procedures concerning the tracer kinetics to verify the usefulness of this approach. The data obtained show good agreement with the values reported in literature. Water as a phantom material is a fairly good general substitute for tissue except for bone and lung. Ground cork was chosen as an equivalent for lung tissue. The phantom provides no facilities for the simulation of bone.

The most important contribution to errors is introduced by the geometrical conditions whereas errors resulting from dosimetry have little effect on the accuracy of measurements. Variation in the depth of the organs was corrected for while size and shape were not considered. Additional studies will hopefully allow a further correction for these sources of error.

An exact description of tracer kinetics in the application of this method is not necessary. It is sufficient to know about the approximate distribution of tracer material to estimate the contribution to the surface dose from various organs. The essential interest of this method is based on the fact that one has not to rely on any kind of kinetic model or data. Therefore it can be expected that this method will yield more reliable data in cases of complex tracer kinetics and will provide a measurement of radiation exposure in individual patients.

Literature.

1a) Loevinger R, M.Bermann : J.Nucl.Med.(MIRD) Suppl. 1, 9(1968)
1b) Ellet W.H.,G.L.Brownell, A.R.Reddy: Phys.Med.Biol.13,219 (1968)
2) Snyder W.S., H.L.Fisher, jr, Mary R.Ford, G.G.Warner: J.Nucl.Med.(MIRD) Suppl.3, 7 (1969)
3) Smith E.M.: Radioactive Pharmaceuticals 6, 649 (1966)
4) Kereiakes R.A. et al: Health Physics 11, 999 (1965)
5) Smith E.M.: Nuclear Med. 6, 231 (1965)