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THE DISTRIBUTION OF SODIUM AND POTASSIUM IN MAN [1]

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Simultaneous measurements of body water distribution and total body electrolyte by the isotope dilution technique permit the calculation of total intracellular electrolyte and average intracellular electrolyte concentration. The application of this principle to the measurement of intracellular sodium and potassium in the dog has been reported by Levitt and Gaudino (1). The purpose of this study is to provide comparable data on man.

METHODS

Total body water was determined by the volume of distribution of antipyrine,[2] corrected for metabolism, by the method of Soberman, Brodie, Levy, Axelrod, Hollander and Steele (2). In view of indirect evidence which suggests that antipyrine may not reach maximal distribution in two hours (3), we have preferred, for extrapolation to zero time in correction for metabolism, to use the plasma concentrations from three to seven or eight hours after injection.

Extracellular fluid was measured by the maximal volume of distribution of sucrose as determined by the calibrated infusion technique (4). Intracellular water was calculated as the difference between the antipyrine and sucrose volumes of distribution. Cellular mass was calculated as the difference between body weight and the weight of the sucrose volume of distribution, and total body solid was calculated as the difference between body weight and the weight of the antipyrine volume of distribution.

Total body sodium was determined by the dilution of Na^{24}. The radioactive sodium was administered by a single injection from a calibrated syringe in an amount equal to 1.3 μc. per kg. of body weight. Radiation incident to the administration of this amount of Na^{24} does not exceed the accepted tolerance dose of 0.1 r/day (5). A period of 24 hours was allowed for complete distribution of the sodium isotope and during this interval all urine was collected. The plasma specific activity (counts/min. per mEq. plasma sodium) at 24 and 25 hours was calculated from the counts/min. per cc. of plasma and the concentration of sodium in plasma (in mEq./cc.) as determined against an internal lithium standard with a Perkin-Elmer flame photometer. After application of the appropriate corrections for radioactive decay, total body sodium (in mEq.) was calculated from the difference between the Na^{24} injected and excreted, divided by the equilibrium specific activity of the Na^{24}. Extracellular sodium was calculated as the product of plasma sodium concentration (mEq./liter) and extracellular fluid volume (liters).[3] Total intracellular sodium was calculated as the difference between total body sodium and extracellular sodium. Intracellular sodium is expressed as concentration per unit of intracellular water (mEq./liter), per unit of cellular mass (mEq./kg.) or per unit of body solid (mEq./kg.).

Total body potassium was determined by the dilution of K^{42}. The radioactive potassium was administered by a single injection from a calibrated syringe in an amount equal to 1.9 μc. per kg. of body weight, a dose which does not produce radiation in excess of the accepted tolerance dose of 0.1 r/day (5). A satisfactory method for preparing the radioactive potassium for injection has been described by Corsa, Olney, Steenburg, Ball and Moore (6). In accordance with the data of these investigators a period of 40 hours was allowed for maximum distribution of the radioactive potassium and during this interval all urine was collected. The specific activity of the plasma was taken as equal to that of the urine (in counts/min. per mEq. of potassium) which was determined on urine samples collected at 36, 40 and 44 hours. Total body potassium was calculated from the difference between the K^{42} injected and excreted, divided by the equilibrium urine specific activity of the K^{42}. Extracellular potassium, intracellular potassium and intracellular potassium per unit of cell water, cell mass and body solid were calculated in a manner similar to that described for sodium.

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[2] The antipyrine used in these studies was supplied in ampoule form through the courtesy of Eli Lilly and Company, Indianapolis 6, Indiana.

[3] A more accurate method of calculation would take into account the volumes of the plasma (PV) and extracellular fluid (ECF), the water content of the plasma (w) and the Donnan factor, k. Taking PV as 4 per cent and ECF as 16 per cent of the body weight, respectively, w as 0.92 and k as 0.95, the calculation as given in the text yields a value for extracellular sodium which is 1.8 per cent too large. Because of its small order this correction has been neglected here.

TABLE I

Intracellular potassium in six subjects

Patient	Age	Sex	Height	Weight	Diagnosis	Total body water	Extra-cellular fluid	Intra-cellular water	Total body solid	Cellu-lar mass	Plasma potas-sium	Total potas-sium	Extra-cellular potas-sium	Intra-cellular potas-sium	Intracellular potassium concentration		
															Per liter cell water	Per kg. body solid	Per kg. cell mass
	yrs.		*in.*	*kg.*		*liters*	*liters*	*liters*	*kg.*	*kg.*	*mEq./l.*	*mEq.*	*mEq.*	*mEq.*	*mEq./l.*	*mEq./kg.*	*mEq./kg.*
K. O.	43	M	67	70.5	Healed burn	36.4	12.4	24.0	34.1	58.1	4.3	2,900	50	2,850	119	84	56
J. M.	44	M	65	72.7	Ear deformity	33.6	12.8	20.8	39.1	59.9	4.2	2,660	60	2,600	125	66	43
W. J.	30	M	63	64.1	Inguinal hernia	38.4	12.5	25.9	25.7	51.6	4.8	2,880	60	2,820	109	110	55
L. I.	15	M	62	47.7	Subcutaneous lipoma	29.7	8.7	21.0	18.0	39.0	4.0	2,050	30	2,020	96	112	52
C. S.	18	F	60	49.5	Subcutaneous fibroma	23.9	9.8	14.1	25.6	39.7	4.4	1,630	40	1,590	113	62	40
F. G.	25	M	65	66.8	Non-toxic thyroid adenoma	35.5	9.6	25.9	31.3	57.2	4.5	2,870	40	2,830	109	90	49
Average															112	87	49

All radioactivity measurements were performed in duplicate on 1 cc. samples which were dried in aluminum planchettes and counted with a shielded end-window Geiger tube. For uniform statistical accuracy, all samples were counted to a 95 hundredths error (7) of less than 5 per cent. Usually, the 95 hundredths error was less than 3 per cent.

The subjects were patients, ranging in age from 13 to 58 years, who were hospitalized for elective surgery except J. T., who was studied 10 days after appendectomy.

RESULTS AND DISCUSSION

Table I presents the simultaneous measurements of body water compartments and total body potassium in six subjects (five male and one female). The calculated values for total intracellular potassium and the concentration of potassium in intracellular water are shown for each subject. Intracellular potassium averaged 112 mEq./liter (range 96 to 125). This value is in good agreement with the average intracellular potassium concentration from four studies in the dog which was 115 mEq./liter (range 109 to 123) (1). No other data on intracellular potassium concentration in man are available. However, Corsa and his coworkers (6) have estimated the intracellular potassium concentration to be 106 mEq./liter (by calculation from an assumed value for the volume of extracellular fluid and measurements of total body water and total body potassium in man).

From the data presented in Table I, the values for intracellular potassium per unit of cellular mass and per unit of body solid may be calculated. Intracellular potassium averaged 49 mEq./kg. (range 40 to 56) of cellular mass and 87 mEq./kg. (range 62 to 112) of body solids.

TABLE II

Intracellular sodium in six male subjects

Patient	Sex	Age	Height	Weight	Diagnosis	Total body water	Extra-cellular fluid	Intra-cellular water	Total body solid	Cellu-lar mass	Plasma sodium	Total sodium	Extra-cellular sodium	Intra-cellular sodium	Intracellular sodium concentration		
															Per liter cell water	Per kg. body solid	Per kg. cell mass
		yrs.	*in.*	*kg.*		*liters*	*liters*	*liters*	*kg.*	*kg.*	*mEq./l.*	*mEq.*	*mEq.*	*mEq.*	*mEq./l.*	*mEq./kg.*	*mEq./kg.*
A. S.	M	58	63	64.6	Inguinal hernia	32.0	10.7	21.3	32.6	53.9	132	2,200	1,410	790	37.1	24.2	14.7
A. M.	M	41	72	84.5	Inguinal hernia	43.7	14.4	29.3	40.8	70.1	137	3,130	1,970	1,160	39.6	28.4	16.5
K. L.	M	49	65	51.3	Hemorrhoids	36.1	11.1	25.0	15.2	40.2	136	2,600	1,510	1,090	43.5	71.7	27.1
C. E.	M	22	71	73.6	Anal fissure	44.8	14.1	30.7	28.8	49.5	138	2,910	1,950	960	31.3	33.3	16.1
J. D.	M	56	64	61.8	Peptic ulcer	34.6	15.5	19.1	27.2	46.3	130	2,660	2,020	640	33.5	23.5	13.8
J. T.	M	13	54	37.2	Post-appendectomy (10 days)	20.3	5.2	15.1	16.9	32.0	136	1,260	705	555	36.8	32.8	17.3
Average															37.0	35.7	17.6

Table II contains the data from the simultaneous measurements of body water compartments and total body sodium in six male subjects. For each subject, the calculated values for total intracellular sodium and concentration of sodium in intracellular water are indicated. The average intracellular sodium concentration for these subjects is 37.0 mEq./liter (range 31.3 to 43.5), a figure close to the average of 36.0 mEq./liter (range 27.5 to 41.0) obtained from four studies in the dog (1). No comparable data are available in man; however, Forbes and Perley (8) have measured total body sodium by dilution of Na^{24} in 32 males and obtained an average of 41.9 mEq./kg. of body weight, a figure to be compared with our average of 37.9.

Values have been derived for intracellular sodium per unit of body solid from the information presented in Table II. Intracellular sodium averaged 17.6 mEq./kg. (range 13.8 to 27.1) of cellular mass and 35.7 mEq./kg. (range 23.5 to 71.7) of body solid.

A direct investigation of the error of measurement by the isotope dilution technique involves the use of total desiccation procedures. Therefore the accuracy of these values for intracellular sodium and potassium in man can only be evaluated in an indirect manner by estimation of the normal values in man and by a comparison which has been made by Corsa and his co-workers (6). They have presented studies of tissue specific activity in rabbits and man which indicate that the total potassium as measured after a 40 hour period of equilibration is within 5 per cent of the actual amount of total body potassium. However, the precise time required for equilibrium distribution of radioactive sodium is not known. It is probable that a certain portion of body sodium (*i.e.*, bone sodium) has not equilibrated in 24 hours, the interval employed in this study.

It should be emphasized that the electrolyte concentrations obtained by these calculations are average concentrations representing all the tissues of the body, and not the concentration in any single tissue.

SUMMARY

Intracellular sodium and potassium have been calculated from simultaneous studies of body water distribution (total body water and extracellular fluid) and total body electrolyte as measured by the isotope dilution technique. The concentration of intracellular electrolyte has been calculated per unit of intracellular water, per unit of cellular mass and per unit of body solid.

Intracellular potassium averaged 112 mEq./liter (range 96 to 125) of intracellular water, 49 mEq./kg. (range 40 to 56) of cellular mass, and 87 mEq./kg. (range 62 to 112) of body solid.

Intracellular sodium averaged 37.0 mEq./liter (range 31.3 to 43.5) of intracellular water, 17.6 mEq./kg. (range 13.8 to 27.1) of cellular mass, and 35.7 mEq./kg. (range 23.5 to 71.7) of body solid.

The average values for intracellular sodium and potassium concentration in man, as determined in this study, are in close agreement with comparable data obtained from studies in the dog and with estimates of intracellular electrolyte in man.

REFERENCES

1. Levitt, M. F., and Gaudino, M., Use of radioactive isotopes to measure intracellular cation concentrations in the normal dog. Am. J. Physiol., 1949, **159**, 67.
2. Soberman, R., Brodie, B. B., Levy, B. B., Axelrod, J., Hollander, V., and Steele, J. M., The use of antipyrine in the measurement of total body water in man. J. Biol. Chem., 1949, **179**, 31.
3. Deane, N., Intracellular water in man. J. Clin. Invest., 1951, **30**, 1469.
4. Deane, N., Schreiner, G. E., and Robertson, J. S., The velocity of distribution of sucrose between plasma and interstitial fluid, with reference to the use of sucrose for the measurement of extracellular fluid in man. J. Clin. Invest., 1951, **30**, 1463.
5. Marinelli, L. D., Quimby, E. H., and Hine, G. J., Dosage determination with radioactive isotopes. II. Practical considerations in therapy and protection. Am. J. Roentgenol., 1948, **59**, 260.
6. Corsa, L., Jr., Olney, J. M., Jr., Steenburg, R. W., Ball, M. R., and Moore, F. D., The measurement of exchangeable potassium in man by isotope dilution. J. Clin. Invest., 1950, **29**, 1280.
7. Jarrett, A. A., Statistical methods used in the measurement of radioactivity. U. S. Atomic Energy Commission Document (AECU-262, MonP-126), June 17, 1946.
8. Forbes, G. B., and Perley, A., Estimation of total body sodium by isotopic dilution. I. Studies on young adults. J. Clin. Invest., 1951, **30**, 558.