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THE ASSAY OF TOTAL POTASSIUM IN THE HUMAN BODY

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Abstract—Total potassium of ten human subjects has been determined by gamma spectrometry following the method of MILLER and MARTINELLI.

Preliminary *in vitro* trials have given an estimation of the different factors influencing the accuracy of the result.

With K^{42} standardization, the results are reproducible with an error of 3.2 per cent. But this standardization introduces conditions which make clinical applications difficult.

We propose a detector with a nearly 4π geometry, formed of a hollow plastifluor cylinder with the photomultipliers located at the end in a crown arrangement.

INTRODUCTION

IF IN the elementary composition of the human being, potassium stands in the seventh place quantitatively, it is the most important element in the living cell after C, O, N and H. Most of the body potassium, being localized within the cells, remains undetected by the ordinary methods of clinical investigation: plasma potassium concentration cannot be considered as a reliable index of body total potassium. The isotope dilution technique, using K^{42}, gives an indication of the amount of exchangeable potassium; but this fraction, important as it is (about 9/10 of total potassium), is variable especially in pathological cases.[1,2]

The gamma radiation of the natural K^{40} isotope, enables the total potassium in the body to be determined with an external radiation counter. During preliminary studies of the clinical use of this technique, we have tried to estimate its accuracy and its limitations, and to find the relevant variables by using the total body counter of the Belgian Nuclear Centre at Mol, the only example now existing in Belgium.

This counter is provided with a NaI(Tl) cylindrical crystal 8 in. diameter and 4 in. high. Its signals are selected by a 256 channel analyzer. The position of the subject relaxing in a tilted armchair is represented in Fig. 1; he is standardized by the ingestion of a known amount of K^{42}.[3]

METHOD

The K^{40} and K^{42} counts were restricted to the photo-electric peaks. The top of the peak is almost in the same channel for both isotopes; the selected channel width here was 11.4 keV and both peaks were counted in the same energy range from 1.32 MeV to 1.65 MeV (twenty-nine channels).

The total number of pulses is printed for each channel and later totalled for all twenty-nine channels. The background value, determined within the same range in the absence of any sample, is 0.696 ± 0.007 counts per sec. For our purpose, this background value is considered to be correct only if the presence of the human subject does not change the count rate in the appropriate twenty-nine channels after deduction of the K^{40} photopeak.

The natural radioactivity of the subject is measured over a period of 3000 sec; a second determination of 1000 sec is performed after the ingestion by the subject of a known quantity of K^{42} (about 1 μC determined by 4π absolute β counting).

PRELIMINARY *IN VITRO* TRIALS

Preliminary trials were performed with solution in plastic containers to compare the count rates given by 1 μC of K^{42} and 1 g of natural potassium placed in the same geometry

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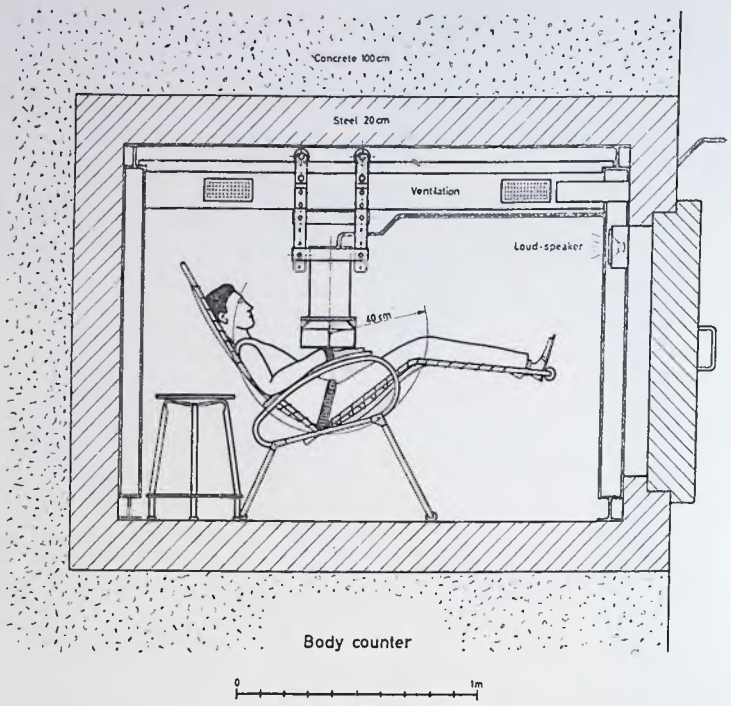

FIG. 1.

relative to the NaI crystal. They have verified that the ratio is independent of the position of the radioactive source and its volume.

To obtain a reproductible geometry, a saddle was used to receive the container. Nevertheless, an additional error of 0.5 per cent was observed in a set of determinations when the container was removed and replaced in the saddle between each determination than when it was left untouched. For 100 g of natural potassium and 3000 sec counting, the standard error was 2.75 per cent when the container has been displaced.

Plastic containers were filled with a 10 l. solution of 100 g of potassium in the form of chemically pure KCl. After an initial radioactivity determination, a known amount of K^{42} was added in the solution and, after homogenisation, the container was replaced in the saddle for a second determination.

A coefficient α can then be calculated:

$$\alpha = \frac{N_{42}}{A_{42}} \cdot \frac{m_K}{N_{40}} \qquad (a)$$

where

N_{40} and N_{42} = corrected count rates due to K^{40} and K^{42},

m_K = number of grams of natural potassium,

A_{42} = amount of K^{42} in μc

The α values were determined for five different positions of the container. Table I gives the mean value with an error of 0.55 per cent and shows that α is independent of the respective positions of sources and detecting crystal.

α being known, it is easy to calculate the amount of natural potassium in a sample by two radioactive determinations, before and after the

Table 1.

Positions	α	σ
1	1894.4	15.8 (0.85%)
2	1814.1	16.5 (0.90%)
3	1897.7	20.2 (1.05%)
4	1885.3	24.7 (1.30%)
5	1875.6	20.3 (0.55%)
Average	1873.4	10.3 (0.55%)

addition of a known quantity of K^{42}:

$$m_K = \alpha \frac{N_{40}}{N_{42}} A_{42} \qquad (b)$$

With 100 g of natural potassium, 1 μc of K^{42}, the counting times recorded above, the accuracy of the α value and the imperfect reproducibility of the geometry between the two determinations, the calculated standard error was 3.2 per cent.

TOTAL POTASSIUM ASSAY IN MAN

α does not depend on the shape, the volume or the position of the container. It can be used, together with formula (b), for the determination of total potassium in man, providing the following conditions are fulfilled:

(a) the patient must be placed in the same position for the counting of radioactivity before and after administration of K^{42};

(b) the amount of K^{42} remaining in the body at the time of the second determination must be accurately known;

(c) at the time of the second counting, the K^{42} must have the same distribution in the body as the natural potassium.

The fulfilment of these conditions has been checked in the following way:

(a) *Reproducibility of the position under the crystal*

The same individual has been submitted to ten successive determinations of the counting rate due to K^{40} in the body. Each measurement was performed during 3000 sec.

The standard deviation obtained on the total number of counts (without correction for the background) in the selected energy range is 1.65 per cent, while statistical error defined by $1/\sqrt{N}$ is only 1.1 per cent. The difference is due to the imperfect reproducibility of the position of the patient.

(b) *Determination of the amount of K^{42} in the body at the time of the second count*

The K^{42}, determined absolutely by $4\pi\beta$ counting and checked for purity by γ spectrometry, is given by mouth to the fasting patient. In these conditions, digestive resorption is complete within a short time. The activity given is below 5 μc at the time of ingestion (the maximum permissable permanent body burden for professionally exposed people is 10 μc).[4]

The urine is collected between ingestion and measurement in the human counter and the K^{42} excreted by this route is subtracted from the quantity ingested. The amounts lost in the sweat and the faeces are neglected.

Suitable corrections for radioactive decay are applied on all results.

(c) *Time necessary for the repartition of K^{42} in the body*

In the course of four experiments (three with the same subject), the decrease of N_{42} with time was studied. Figure 2 shows the results (corrected

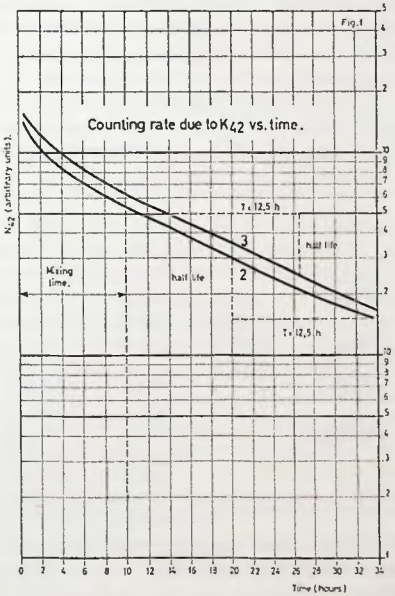

Fig. 2. Counting rate due to K_{42} vs. time.

for losses in the urine), in semi-logarithmic scale. All the curves have the same shape: they begin with a relatively rapid decrease but, after 10 hr, the line becomes straight with a slope depending only on the physical half-life (of 12.5 hr) of the radionuclide.

Although we know that equilibrium can exist only within the pool of exchangeable potassium, we admit that when the curve has straightened, the repartition of K^{42} is sufficiently analogous to that of the body total potassium to serve as a useful standard.

In subsequent work, the second radioactivity determination was done about 24 hr after the ingestion of K^{42}.

REPRODUCIBILITY OF THE BODY TOTAL POTASSIUM ASSAY

The same patient was submitted to three successive determinations at two weeks intervals to give time for the K^{42} activity to disappear completely between two determinations. Each ingestion of K^{42} was followed by the countings.

The recorded error of 3 per cent is within the expected range. On the other hand, small time variations have no significant influence on the result.

Table 2

♂ 28 years		1.81 m	87 kg
	H	m_K	$\frac{m_K}{W}$
Exp. 1	21.10 h	144 g	1.65 g/kg
	24.25 h	150 g	1.72 g/kg
Exp. 2	21.50 h	151 g	1.74 g/kg
	23.35 h	153 g	1.76 g/kg
Exp. 3	25 h	157 g	1.80 g/kg
	27.30 h	155 g	1.78 g/kg
Averages		152 g	1.74 g/kg
		$\sigma = 4.5$ (3%)	$\sigma = 0.05$ (3%)

H = time elapsed between ingestion and counting.
m_K = total potassium in grams.
$\frac{m_K}{W}$ = grams of potassium per kilogram of body weight.

COUNTING TEN SUBJECTS

Ten men in good health have been submitted to total potassium determination following the technique here described (see Table 3).

The figures obtained of 1.77–2.19 g of total potassium per kg of body weight are in agreement with data found in the literature.

Subject 1 gave an abnormal result which can be explained by previous radioactive contamination with a small amount of Zn^{65} (energy of $\gamma = 1.114$ MeV) (the contamination was 0.025 per cent of the tolerance level). The Zn^{65} peak partially covers the K^{40} peak and so increases the N_{10} value. This clearly indicates a limitation of the method: the patient must not be contaminated with a gamma emitter of similar or higher energy than K^{40}.

It can be seen that the count rate per gram of potassium (N_{40}/m_K) has a standard error of 7.5 per cent because of different geometries and absorptions although the individuals used in the experiment, as far as physical appearance was concerned, were not extreme cases.* The method with two determinations and absorption of K^{42} has an error of only 3 per cent.

DISCUSSION

Our purpose is the clinical application of the determination of total potassium by γ spectrometry. We have studied the conditions of the utilization of this method and its accuracy with the equipment that was at our disposal.

The accuracy calculated from *in vitro* experiments and checked on human individuals is good, but the determination is dependent on a set of conditions which make the method unpractical for clinical use.

The major source of error is the difference in the crystal–patient relative geometry due to physical differences between human subjects; this is clearly shown by the very different values

* It must be remembered that this standard deviation of 7.5 per cent contains 2.25 per cent for the reproducibility of counting with the same patient; only the rest is due to differences in sizes and shapes between human beings. It seems that MILLER has been able to reduce this latter part of the standard deviation to only 2.5 per cent by using both the photoelectric peak and the Compton region between 0.775 and 1.275 MeV and positioning the crystal farther from the subject.[5]

Table 3

Patients	W	H	N_{40}	R_U 24 h	m_K	$\frac{m_K}{W}$	$\frac{N_{40}}{m_K} \cdot 10^2$	%
1-C	61	170	2.363	5.0	157 ± 5.3	2.57 ± 0.08	1.508	+0.6
2-M	64	181	2.065	2.2	140 ± 4.7	2.19 ± 0.07	1.475	−1.5
3-K	65	172	2.128	12.5	122 ± 4.0	1.87 ± 0.06	1.751	+17
4-V	70	170	2.340	5.0	151 ± 5.0	2.15 ± 0.06	1.553	+3.7
5-L	72	175	2.129	2.4	127 ± 4.2	1.77 ± 0.05	1.670	+11.5
6-B	74	170	2.033	2.3	145 ± 4.9	1.96 ± 0.06	1.398	−6
7-S	78	180	2.057	3.6	144 ± 4.9	1.84 ± 0.06	1.430	−4.5
8-G	78	180	2.184	3.4	150 ± 5.0	1.88 ± 0.06	1.456	−2.8
9-Bn	80	186	2.360	3.7	160 ± 5.3	2.00 ± 0.06	1.473	−1.6
10-D	87	181	2.192	3.7	159 ± 5.3	1.80 ± 0.06	1.459	−2.6
			2.067	4.2	150 ± 5.0	1.72 ± 0.06	1.353	−9.5
			2.276	5.0	153 ± 5.0	1.76 ± 0.05	1.452	−3.1

W: weight in kg.
H: height in cm.
N_{40}: count per second due to the total natural potassium.
R_U 24 h: K^{42} lost in urine during the 24 hours interval, in per cent.
m_K: weight in grams of total potassium; the deviation is calculated on the basis of a 3% error.
$\frac{m_K}{W}$: grams of potassium per kg body weight.
$\frac{N_{40}}{m_K}$: number of counts per second per gram of natural potassium, with the per cent deviation from the mean. The average is $1{,}498 \cdot 10^2$.

obtained for the quotient N_{40}/m_K with individuals that were physically not very different. The standardization with K^{42} which gives an α coefficient independent of physical differences between patients, is an elegant means of overcoming this difficulty, but it necessitates two radioactivity determinations at a 24 hr interval, which makes an urgent analysis impossible; moreover, sufficient time must elapse (a few days) between two determinations so that the K^{42} ingested for a first determination has completely disappeared before the undertaking of the second: frequent monitoring of the same patient is thus not possible. The technique requires several manipulations which produce an accumulation of errors.

Because of these shortcomings, we have chosen, for new equipment to be built in Liège University Hospital, a 4π geometry unit similar to that of the liquid scintillator of Los Alamos.[6] Such a counter for routine estimation of total potassium should have the following advantages:

(1) reduction of the counting time for the same statistical error of N_{40} (an advantage which is very important in clinical work);

(2) elimination of the K^{42} standardization with the possibility of urgent determinations and frequent repetitions;

(3) final result obtained after only one determination and consequently no accumulation of errors.

In this future project, the detector will be a hollow cylinder of plastifluor into which the patient will be introduced by means of a gliding trolley. The photomultipliers will probably be located at the two ends in a crown arrangement; the analyser will have only ten channels.

The poor spectrometry will however allow K^{40} and Cs^{137} to be distinguished; there will be no difficulty in tracer studies utilizing one radionuclide at a time. No other human counter of this design has been built to our knowledge; the principal innovation is the substitution of liquid scintillator by a plastifluor.

The first part of this work has been published in the Proceedings of the symposium on "Whole Body Counting" held in Vienna (Public. I.A.E.A., Vienna 1962).

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