CCXXXII. THE ASSIMILATION OF ALUMINIUM BY THE HUMAN SYSTEM.

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THE scientific work relating to the assimilation of aluminium by the animal system has for the most part failed to give satisfaction, even when by weight of evidence it was fairly conclusive. The chief reasons for this are that the quantities of aluminium absorbed are very small, frequently much less than one part in a million parts of blood or tissue and rarely appreciably more, while the purest reagents obtainable normally and employed in making the search can very rarely if ever be obtained quite free from the element in question. The weight of aluminium present in the necessarily large mass of reagents is often greater than that in the material to be extracted.

Attempts to simplify this problem by resort to the spectrograph are presented in the following observations.

The first experiments were directed to discovering how much, if any, aluminium is present in normal blood obtained first from the slaughter-house and then from man, and to finding and estimating suitably small quantities of aluminium mixed well into the blood before drying down.

The experimental procedure ultimately adopted was to ash a few grams of blood in a new silica crucible after it had been prepared by treatment with hydrochloric acid followed with hot concentrated sulphuric acid. The blood was gently ignited until free from carbon; then 10 mg. of the ash, representing approximately 1 g. of blood, were transferred to the lower electrode of an arc-lamp and the spectrum observed in the usual way by means of a large Hilger quartz spectrograph.

Under the conditions of experiment the two principal aluminium lines 3961.540 and 3944.032 Å. were well in evidence, although feeble, when the proportion of added aluminium was one part in a million parts of blood. The lines were still definitely discernible when the concentration was only one-fifth of that named, and in the later experiments with one in ten millions they could be recognised with certainty.

The absence of extraneous aluminium was assured by (a) cleaning the crucible as above described, (b) using no reagent, and (c) taking a comparison spectrogram of the electrodes alone immediately before placing thereon the ash, to serve as a blank. There is one necessary condition which may at first

sight appear to contradict these tenets, namely, the moistening of the ash with a few milligrams of dilute acid, but as the electrodes were similarly moistened, the blank (*c*) was complete; no aluminium was or could be discovered in the 3 or 4 mg. of acid used, even if it did contain the amount of aluminium said to be present in ordinarily pure reagent acid.

Under the conditions of experiment, sheep's blood was usually found to contain about 1-2 parts per million aluminium; human blood was almost invariably free, that is, it contained less than one part in five or ten millions, although occasionally a very small quantity was indicated.

A series of trials with blood charged with various known quantities of aluminium, round about one part per million, showed a well-graduated series of intensities corresponding with the quantities of element added and gave full assurance that the quantitative indications were satisfactory within the limits shown in the following Tables.

In order to ascertain whether aluminium is taken up by the blood from food two men were dieted for 24 hours or more with food supposed to be free from aluminium; then each of them partook of a meal containing a definite quantity of aluminium. Just before the meal a sample of blood was taken; 3 hours after the meal a second sample, a third $4\frac{1}{2}$ hours after, and a fourth sample 48 hours after. Each sample of blood was then carefully ashed and submitted to spectrographic examination.

The results were that no aluminium could be detected in the first normal samples of blood, nor indeed in those taken 3 hours after the meal. In the case of one subject no aluminium was found in either of the two succeeding samples, except a minute trace after 48 hours. With the other subject traces were discovered after $4\frac{1}{2}$ hours and rather more after 48 hours, but the quantity was very small, probably not more than one part of aluminium (Al) in five and three million parts of blood respectively.

Taking several specimens of blood from the same subject was very trying; and when it was found that normal human blood contains usually no aluminium, or only a minimal quantity, it was decided to take advantage of blood from patients undergoing operations, feeding them with aluminium-containing food before or after the operation according to the nature of the specimens required. This procedure eliminated the drawing of more than occasional special specimens of blood. Several patients awaiting operation had included in their daily diet for a convenient number of days one meal of scones containing about 94 mg. of aluminium, the rest of the diet being normal. This course had an important advantage in the patient remaining normal in temperament and digestive function during the ingestion of the aluminium. Blood was taken some time before commencing the feeding and 24 hours after the last meal.

Assuming that there are about 6 kg. of blood in the human body, the proportion of aluminium in the blood, supposing the whole of the aluminium passed into the blood-stream, would be about 15 parts per million, but this is

of course impossible of realisation, and all considered, not more than a tenth of this amount is likely to appear in the blood.

The observations on the analysis of blood were of three types: (a) normal blood; (b) normal blood into which known quantities of aluminium had been mixed before drying down; (c) blood from subjects who had been fed on aluminium-containing scones.

Preliminary tests, made during the development of the method, are collated in Table I. In the earlier ones, the limit of sensitivity was about 1 in 3,000,000, but in the later ones, the limit was 1 in more than 10,000,000. "W." signifies a particular hospital.

Table I.

Subject	Aluminium—parts per million		
	In normal blood	Added	Found
W. 1	6 times 0 3 times say 0.1 or 0.2	—	<i>v. infra</i>
W. 2	0	—	—
W. 3	0	1	1.0, 0.6, 1.4, 1.0
W. 4	0.0	1	1.4, 1.0
W. 5	0.0	3	<i>v. infra</i>
W. 6	0	3	<i>v. infra</i>
W. 7	0	—	<i>v. infra</i>
W. 8	0	3	3.0, 3.0
W. 9	—	3	3.0, 3.0, 3.0, 3.0
W. 10	0	1	1.0
W. 11	0	1	0.6

W. 5 and 6. The method for the aluminised ash was modified, with a view to concentrating the Al, by washing away the soluble portion. The results were unduly low, 1.7 and 1.4 respectively, whence it is assumed that the aluminium is partly in a soluble form, possibly as alkaline aluminate, but this was not studied.

W. 7. 8 g. of this specimen were ashed at full temperature in a closed apparatus, in which the vapours evolved were aspirated through water contained in absorption tubes, to ascertain whether any iron was thus vaporised in the form of ferric chloride. No iron was detectable in the distillate by the usual reagents. From this it was inferred that since iron is not volatilised under the conditions, it is probable that aluminium would not be volatilised.

Blood from two sheep was examined. Numerous preliminary experiments showed that the blood from sheep No. 1 contained about 3 parts of Al per million; that from sheep No. 2 about 1 part.

Results of the principal series of experiments on human subjects are collated in Tables II and III. They demonstrate that aluminium is absorbed by the blood of a subject who eats food containing aluminium, and that the amount absorbed does not increase appreciably by continuing the feeding, unless one case ("L") is to be regarded as representative of a certain class of subjects.

"N" shows an exceptionally high figure before feeding, and "G" excep-

tionally low after feeding. The extraordinarily high results with "L" cannot be explained; the surgeon believed the specimen to be satisfactory. In the cases of " α " and " β " the numbers in brackets signify the number of hours after the single meal was taken. The fifth exps. with α and β were by a special method, and the indications were so slight as to be doubtful.

The increase in the aluminium content of the blood is in some degree a measure of the quantity of aluminium which has passed into the blood-stream.

Table II.

Subject	Sex and age	Aluminium found before feeding		
		1st exp.	2nd exp.	Adopted
α	M.	0	0	0
		0 (3rd exp.)	0 (4th exp.)	—
β	M.	0	0	—
		0 (3rd exp.)	0 (4th exp.)	0
A	M. 56	0.3	0	0.15
B	M.	0	—	—
E	—	0	—	0
G	M. 25	0	—	0
L	F.	0.1	—	0.1
M	F.	0	—	0
N	M. 25	0.2	0.3	0.25

Table III.

Subject	No. of daily meals	Aluminium found after feeding, parts per million			
		1st exp.	2nd exp.	3rd exp.	Adopted
α	1 (3)	0	0	0	0
		0	0.1	—	—
		(4th exp.)	(5th exp.)	—	—
	1 (4½)	0.3	0.4	0.2	0.3
	1 (48)	0.5	0.1	—	0.3
β	1 (3)	0	0	0	0
		0	0.1	—	—
		(4th exp.)	(5th exp.)	—	—
	1 (4½)	0.2	0.1	0.1	0.1
	1 (48)	0.3	0.7	—	0.5
A	1	1.2	1.1	1.3	1.2
B	2	0.4	0.2	0.2	0.3
E	5	0.2	0.2	0.5	0.3
G	7	0	0.1	0	0.03
L	12	5	4	—	4.5
					(<i>v. infra</i>)
M	13	1.2	0.7	1.3	1.1
N	14	0.2	0.2	0.6	0.3

To what extent it is a measure is uncertain at present, because there are no data showing how quickly the aluminium is eliminated again. The observations with the subjects α and β signify that the passage is not very rapid, since it was not until 4 or 5 hours after feeding that the element was first discoverable, nor is the elimination very rapid, seeing that the aluminium lines were stronger at the end of 48 hours than after 4 or 5 hours. The results with subject A are in harmony with the foregoing; at the end of 24 hours the spectrograph revealed quite a substantial proportion, an increase of at least one part per

million. A notable feature of the results is that the quantity of aluminium after feeding is the same however many days the feeding has been continued.

Aluminium absorbed by the milk.

Experiments were made on two women, three cows and one goat. One of the cows and the goat were used twice, at times sufficiently far apart to allow of their being considered separate subjects, making in effect eight in all.

The order of experimenting was in general similar to that followed with blood. The aluminium was administered in combination with the food, as for the blood inquiry. In the case of cows turned out for the summer they were drenched with $\frac{1}{2}$ oz. of alum.

All the results (Table IV) show clearly that aluminium passes fairly rapidly

Table IV. *Aluminium in milk.*

Subject	Before or after feeding	Dose, as alum	Interval (hours)	Al found; parts per million		Remarks
Cows:						
"Gay"	Before	—	—	(a) 0	(b) 0	After drenching with alum (in June)
"	"	—	—	(c) 0.3	(d) 0	
"	After	(1¼ ozs.)	9	(a) 0	(b) 0.4	
"	"	—	—	(c) 0.3	(d) 1.0	
"Brindle"	Before	—	—	(a) 0.3	(b) 0	"
"	"	—	—	(c) 0	(d) 0.1	"
"	After	(1¼ ozs.)	9	(a) 0.5	(b) 0.7	"
"	"	—	—	(c) 0.3	(d) 0.1	"
"Gay"	Before	—	—	(a) 0.2	(b) 0	—
"	After	1½ ozs.	9	(a) 0.9	(b) 0.4	—
"Cowslip"	Before	—	—	(a) 0	(b) 0.1	—
"	After	1½ ozs.	9	(a) 0.8	(b) 0.5	—
Goat A	Before	—	—	(a) 0	(b) 0	—
"	After	⅔ oz.	5½	(a) 0	(b) 0	—
Goat B	Before	—	—	(a) 0	(b) 0	—
"	After	½ oz.	14	(a) 0.3	(b) 0.2	—
Human A	Before (?)	—	—	(a) 0.1	(b) 0.1	As judged by the results these two samples have been transposed; possibly in the nursing home
"	After (?)	28 grains	3½	(a) 0	(b) 0.02	
Human B	Before	—	—	(a) 0	(b) 0	
"	After	28 grains	2	(a) 0.05	(b) 0.15	

into the milk. The procedure was to take the first sample of milk just before feeding with aluminised food, and the second sample from the next milking several hours later.

The intervals in the case of the human specimens were very short, and it is quite likely that this accounts for the negative results with subject A, especially with so small a dose, but it may be these two samples were transposed somehow, possibly in the nursing home.

It is interesting that the goat showed no absorption of aluminium the first time, and very little the second, although the dose was fairly large for the size of the animal.

The quantities found compare quite well among themselves if one omits two or three anomalous figures for the cows which were drenched, but with

these first specimens the work was largely of the nature of trial, and might quite fairly be omitted from the report, but they are included so that the whole of the information gleaned may be available.

There are various conditions to be observed in a closer study of the subject; for example, to discover the best interval between the time of feeding and the following milking, and whether the aluminium appears in the earlier or the later stages of the secretion. Also we have no knowledge as to how far the magnitude of the dose or its repetition affects the results. This is a matter of great physiological interest.

SUMMARY.

1. The chief feature of this inquiry is the application of the modern quartz spectrograph, in the absence of all reagents, to the estimation of aluminium in tissues.
2. It has been demonstrated that normal blood usually contains no aluminium, and when it does contain any, the proportion is very small.
3. A considerable quantity of aluminium is found in the blood of the same person after feeding with even one meal of aluminium-containing food.
4. Similar observations apply to the milk.