KETONURIA IN THE ANTARCTIC: A PRELIMINARY STUDY

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ABSTRACT. Excretion rates for total ketone bodies were measured on five fit men during winter sledging activities in the Antarctic. Ketonuria occurred in all subjects.

Energy expenditure and dietary intake were estimated. Whilst sledging, high excretion rates of total ketone bodies were usually obtained on days of high energy expenditure. At the station, or when lying-up weather bound, excretion rates fell. Specific rises can be related to individual variations in physical activity. The low excretion rates of total ketone bodies on the last and coldest journey suggest that some acclimation may have occurred.

KETOSIS was first defined as an abnormal condition in which acetone, aceto-acetic acid and β-hydroxybutyric acid appeared in the blood and urine. However, as more sensitive means of analysis were developed, it was shown that blood and urine are never free from these substances. An upper normal limit for total ketone bodies of 1·4 mmol./l. for serum and 5 μmol./min. for urinary excretion has been suggested by Johnson and others (1958).

Passmore (1961), in a review on ketosis, summarized the factors likely to produce ketosis. Diets either high in fat content or low in total calories are likely to produce ketosis. Truly obese people have been reported to be relatively resistant to the ketosis of starvation (Kekwick and others, 1959). Sargent and others (1958) showed that subjects exposed to low temperatures were likely to become ketotic. Exercise also influences ketosis. Courtice and Douglas (1936) demonstrated ketosis occurring in the post-absorptive state after prolonged moderate exercise, and the findings of Passmore and Johnson (1958) confirmed this.

Polar travel has exposed Man to arduous work in low ambient temperatures. Despite improvement in logistics, travel by dog sledge is still limited by the amount of food available. To supply a diet of light weight but of high calorie value, rations of high fat content must be used. This paper reports a study on five members of the British Antarctic Survey who took part in sledging activities from Stonington Island (lat. 68°11′S., long. 67°00′W.) during 1964.

Setting of investigations

The British Antarctic Survey station at Stonington Island is small (11 men) and it is situated in the Neny Fjord area of Marguerite Bay on the west coast of the Antarctic Peninsula. From this station, topographical, geological and geophysical surveys are undertaken. Four winter sledge journeys were studied; they were undertaken to establish depots for the summer field programme and involved hauling loads of several tons on to the high plateau separating the west and east coasts of the Antarctic Peninsula. Dog teams were the main motive force. Where the going was too steep for dogs, manpacking was used. Because of the nature of the terrain and the weather, the journeys consisted of days of hard work broken by periods of complete inactivity. Daily life to be expected in such conditions has been described elsewhere (Walton, 1955).

Subjects

The five subjects were all healthy males, aged between 23 and 31 years. Details are given in Table I. Only subject A took part in all four journeys.

Diet

Records were kept of all food consumed during the period of study. From these records estimates were made of total calorie intake and the percentage of calories derived from fat. On the Antarctic stations, canned or dehydrated foods were eaten and much inventiveness was shown in cooking. Fresh bread was made daily. The field rations were those of the British Antarctic Survey sledging rations, supplying 4,300 kcal./day, of which 57 per cent were derived from fat.

Estimate of energy expenditure

Throughout the period of study, time and motion record cards were kept, activities being entered in 5 min. periods. Whilst at the station subjects kept a note of their own activities. In the field, as the activity patterns of travelling companions are virtually identical, only one

TABLE I. SUBJECT CHARACTERISTICS

Subject	Age (yr.)	Height (cm.)	Weight (kg.)	Surface area (m.^{2})	Fitness score* Autumn	Mid-winter
A	27	181	82·1	2·00	78	95
B	31	186	85·0	2·10	85	98
C	25	191	79·5	2·08	100	97
D	23	178	70·5	1·86	95	95
E	23	170	72·5	1·82	—	—

* Harvard pack test performed before autumn sledging and during mid-winter. (Poor below 40; average 41–75; good 76–90; superior above 90.)

record was maintained. Estimates of energy expenditure were made from energy-cost tables (Passmore and Durnin, 1955). Energy expenditure on activities peculiar to polar regions was assessed by measuring pulmonary ventilation. A Wright's respirometer (Wright, 1955) was incorporated on the inflow side of a face mask (U.S.A.A.F. pattern), inspiratory air being measured to avoid condensation and freezing problems. Even with this arrangement, ventilation studies could not be undertaken in very low temperatures. From the corrected volume of inspired air, an estimate of the rate of energy expenditure (E) in kcal./min. was made assuming an expired air oxygen of 16·3 per cent.

Thus
$$E = \frac{4 \cdot 92}{100} \dot{V} \left[(20 \cdot 93 - 16 \cdot 3) - 0 \cdot 03 \right],$$

where $\dot{V}$ is the corrected gas volume in l./min. (Passmore and Draper, 1964). Measurements were made on only one subject but the particular task was repeated as often as possible at differing temperatures, wind speeds, and snow conditions. The mean energy-cost estimates for these activities are given in Table II. The subject was later exercised on a motorized treadmill on return to the United Kingdom and expired air was collected at widely varying ventilation rates, a mean expired air oxygen of 16·3 per cent being obtained.

Meteorological data

Wind velocity was recorded using a hand-held cup anemometer. Barometric pressure was measured with an aneroid barometer checked against the station mercury barometer. Dry-bulb temperatures were recorded.

Collection of urine

Urinary specimens were collected in the late evening and the volume measured. The time was noted and also the time interval since the bladder had last been emptied. Approximately 15 ml. were placed in a universal container and allowed to freeze. Subsequent dilution to correspond to a urinary excretion rate of 3 ml./min. was made in the laboratory. Specimens were kept frozen until laboratory examination was possible.

Quantitative analysis

The method used was a modification of that described by Johnson and others (1958); 9 ml. of 0·09 *m* metaphosphoric acid were placed in a cone-tipped centrifuge tube, and to this was added 1 ml. of urine, the contents being mixed by inversion; 4 ml. of this were placed in a glass ampoule and 1·3 ml. of sulphuric acid–dichromate mixture were added. The ampoules were then sealed and autoclaved at 15 lb./in.^{2} (1·06 kg./cm.^{2}) for 1 hr. After cooling, the mixture was analysed by the method of Thin and Robertson (1952) in which acetone diffused in a Conway plate into alkaline salicylaldehyde. The intensity of the final colour was measured. With each run reagent blanks and a series of calcium zinc hydroxybutyrate standards were included. The reproducibility of the method with standard solutions was within $\pm$ 4 per cent.

TABLE II. ENERGY EXPENDITURE OF VARIOUS ACTIVITIES IN THE ANTARCTIC

	(kcal./min.)
Repairing sledge	3·2
Geologizing	3·9
Descending slope	4·2
Skiing with sledge	4·8
Pitching camp	5·5
Breaking camp	5·7
Outside camp duties	6·6
Walking alongside sledge	6·9
Running and sitting with sledge	7·1
Chopping snow blocks	7·5
Ski-marching	8·0
Walking with sledge (breakable crust)	8·6
Walking uphill	8·6
Chopping seal	9·5
Manhauling uphill	15·2

Pushing sledge } Ventilation rate in
Manpacking with 70 lb. (31·8 kg.) loads } excess of 60 l./min.

Height of subject 181 cm.
Weight of subject 82·1 kg.
Age of subject 27 yr.

RESULTS

The results in the four journeys undertaken are presented in Fig. 1. Individual excretion rates of total ketone bodies are shown in relation to mean dietary intakes and mean energy expenditure. For convenience, days have been classified as at the station (B), sledging (S) and lying-up (L).

Whilst at the station, energy expenditure varied between 2,500 and 4,000 kcal./day. In order to minimize individual variation both subjects usually performed similar tasks. This was not always possible, and subject D spent day 1 of journey 3 away from the station hunting for seals and his energy expenditure for that day was considerably higher than that of subject A. In the field, tasks usually have to be performed in pairs and there was little scope for individual variation in energy expenditure. Winter journeys are inevitably broken by periods of bad weather when travel is impossible. During these days spent "lying-up", activities consisted of low-energy work such as repairing sledges or dog harnesses, or reading and writing. On such days the only high-energy work consisted of brief and unpleasant visits out of the tent to tend the dogs. Energy expenditure on lie-up days was estimated to be about 2,200 kcal./day. Whilst sledging, where relatively flat terrain was encountered, energy expenditure was approximately 4,000 kcal./day. In other steeper areas considerable manpacking was involved and energy expenditure estimates rose to 6,500 kcal./day.

The mean dietary intake at the station was 3,700 kcal./day, of which 47 per cent was derived from fat. In the field, virtually the full sledging ration was eaten by all the subjects and there was very little plate wastage. An extra bar of chocolate was sometimes consumed. Mean

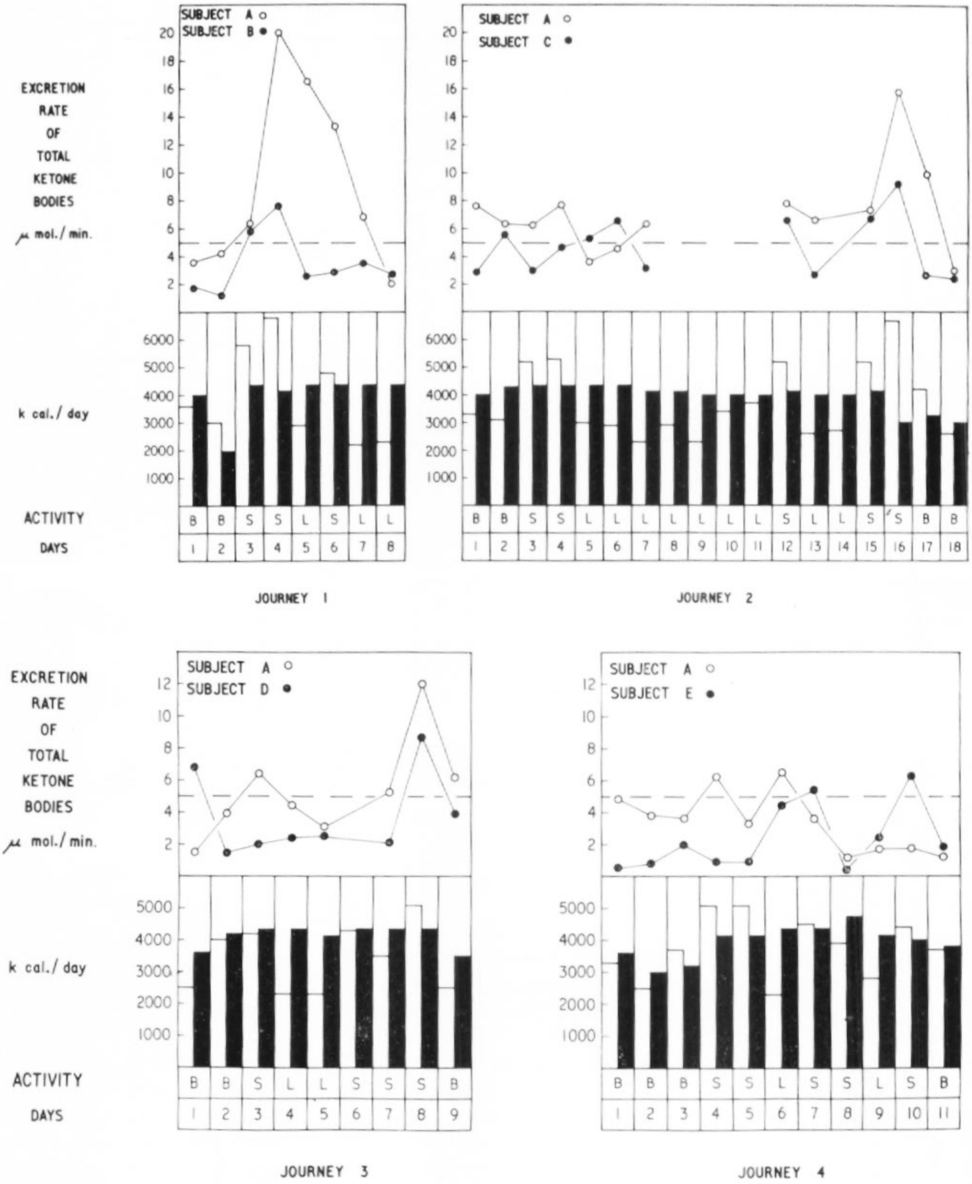

Fig. 1. Daily excretion rates of total ketone bodies plotted against energy balance. Mean energy expenditure is represented by the open columns; the closed columns represent calorie intake. Activity pattern for the day is represented by B (station), S (sledging) and L (lying-up).

dietary intake in the field was almost always around 4,300 kcal./day but it was difficult to prevent individual taste differences. For example, subject A took no sugar in coffee or tea.

Individual excretion rates of total ketone bodies varied considerably. At one time or another all the subjects exhibited ketonuria as defined by Johnson and others (1958), i.e. excretion rates above 5 μmol./min. High excretion rates usually correspond to days of high energy expenditure, although there sometimes appeared to be a "hangover" effect with ketosis persisting on the following day. The Student "t" test was used to compare excretion rates of ketones at the station and during lying-up with excretion rates whilst sledging. Ketosis was associated with days spent sledging: a t value of 2·667 on 78 degrees of freedom was obtained; this comprises a "significance level" of 2 per cent, but in view of the considerable degree of dependence thought to obtain between observations this can only be regarded as an indication of trend. Because of the individual variation in energy tasks at the station or during lying-up, and the difficulty in estimating this, only the association between energy expenditure whilst sledging and ketosis was examined. In Fig. 2, energy expenditure whilst sledging is plotted against ketone excretion rates. The correlation coefficient is 0·6238 on 32 pairs of observations ($P<0·001$).

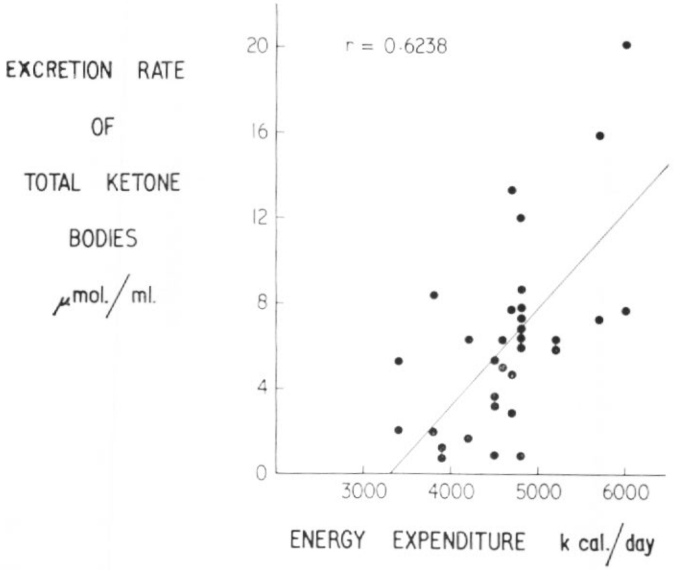

Fig. 2. The excretion rate of total ketone bodies plotted against energy expenditure whilst sledging.

Four of the five subjects had lost weight (1·0–1·5 kg.) on return to the station. This weight was regained within 48 hr. All the subjects complained of excessive thirst after return to the station; thirst was not prominent in the field.

The days spent sledging were also those spent exposed to low environmental temperature. However, on journey 4 the lowest temperatures were recorded and it was only on this journey that sleep was made difficult by the cold. On this journey excretion rates for total ketone bodies were low.

Discussion

The mechanism of the ketosis is uncertain. All the subjects were exposed to cold and were living on a high-fat diet. High excretion rates for total ketone bodies mainly occurred on days of high energy expenditure. On these days, despite high calorie intake, the subjects were in negative calorie balance; the ketosis could be akin to that of starvation. At the station, ketosis was less common and individual variations can be explained on differences of activity pattern. For example, subject E exhibited ketonuria on the first day of journey 3. This was the day he had spent away from the station hunting for seals.

Ketosis diminished on lie-up days when the dietary intake was the same as during sledging. It is unlikely, therefore, that the high-fat diet plays a prominent part in the production of ketosis. However, modification of the diet might be effective in lessening the degree of ketosis. Rogers and others (1966) have shown that sucrose supplementation lessened ketonuria and hypoglycaemia in survival experiments. Similar amelioration was not noted in subjects on meat bar supplementation. Thus additional carbohydrate in the sledging rations could lower the excretion rates of total ketone bodies. Subject A exhibited high levels of ketonuria but he took no sugar in tea or coffee.

The effect of temperature is difficult to assess. Days of high energy expenditure usually corresponded to days of cold exposure. However, on journey 4 the lowest temperatures were recorded; on this journey ketone excretion rates were also low. In the setting of continuous low temperatures, lowering the environmental temperature still further may have little effect on ketonuria. Alternatively, some measure of adaptation may have taken place. Such adaptation to ketosis was demonstrated in rats by Scott and Engel (1953). They showed that rats readily developed ketosis on exposure to cold, but if they are acclimatized to 4° C before being fasted at the same temperature ketosis does not occur. A similar observation was made in Man by Hanson and Johnson (1965). They exposed semi-nude men to 0° C for 90 min. once a week for 3 weeks. In the first week there was an increase in plasma ketones during cold exposure, but plasma ketones were not increased during the second and third weeks. It is possible that cold acclimation may prevent fasting ketosis by an increased capacity to utilize ketone bodies.

Further investigation into the biochemical changes during prolonged or repeated cold exposure may determine whether true cold acclimation occurs in Man.

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