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ARCTIC SURVIVAL RATIONS

III. THE EVALUATION OF PEMMICAN UNDER WINTER FIELD CONDITIONS

TECHNICAL REPORT 58-6

LADD AIR FORCE BASE

A L A S K A

PUBLICATION REVIEW

This report has been reviewed and is approved.

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ARCTIC SURVIVAL RATIONS

III. THE EVALUATION OF PEMMICAN UNDER WINTER FIELD CONDITIONS

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ABSTRACT

Pemmican, a dehydrated high-fat, high-protein, carbohydrate-free meat preparation was fed, with and without an isocaloric supplement of sugar, to 10 human subjects undergoing simulated survival in a severely cold environment for 9 days. No ill effects were noted that could not be attributed to caloric restriction, and the performance of the subjects was considered adequate for survival situations involving moderate activity. An isocaloric supplement of 40 grams of sugar increased the fasting blood-sugar levels, decreased the nitrogen balance, and decreased the excretion of ketones. During the 3 days following initiation of the dietary regimen, fasting blood-sugar levels and daily nitrogen balances fell precipitately, while ketone excretion rose. After this, however, the blood-sugar levels rose somewhat and leveled off, the nitrogen balance increased appreciably, and excretion of ketones fell gradually to quite low levels irrespective of the isocaloric supplement of sugar. These results have been interpreted to mean that the subjects were becoming adapted to the combination of pemmican and restricted caloric intake.

THE EVALUATION OF PEMMICAN UNDER WINTER FIELD CONDITIONS

INTRODUCTION

The choice of an emergency ration for airmen faced with the problem of survival after a bailout or crash landing is of great importance. The most pressing consideration is the need for a ration containing a maximum concentration of calories within the alloted storage space. The ration must not be subject to spoilage and should not cause any metabolic disturbances which would hamper the activities of the survivor.

Pemmican, a dehydrated, high-fat, high-protein food, furnishes more calories per unit volume or weight than perhaps any other available foodstuff. In addition, it has excellent keeping qualities, even with very simple packaging. In its various forms, pemmican has had a long and illustrious history as a trail ration and has been highly recommended for modern use as a survival ration (17). While the results of recent investigations (6) have been interpreted as casting serious doubts on its adequacy as a survival ration, there remains some question as to the relevance of these studies to the survival of aircrews in the Arctic. Survival rations are, or should be, designed to meet a very specialized need. Too frequently they are evaluated against standards more applicable to field or trail rations. Preliminary studies in this laboratory (2) have indicated that pemmican has been unjustly maligned, and that under conditions of restricted caloric intake along with reasonable but not excessive activity, it may meet the survivor's most important requirement. That is, it may keep him alive longer than would the same amount of any other food. Presumably by the time he is actually reduced to eating it, this will be more important to him than the admittedly higher palatability of other foods.

These experiments have also indicated that the replacement of a small amount of pemmican isocalorically with sugar would have the following effects:

1. An increase in fasting blood sugar.
2. A decrease in the negative nitrogen balance.
3. A decrease in urinary ketone body production.

Most of the subjects participating in these preliminary studies had the subjective feeling that the sugar supplement decreased hunger pains and the associated nausea which often occurs in the early stages of the pemmican regimen.

The experiments reported in this paper were planned to determine whether men can function adequately for a reasonable length of time under realistic survival conditions on a calorically restricted diet consisting almost entirely of pemmican. A further purpose was to measure some of the effects of a small sugar supplement to the basic pemmican diet. Attention in these particular experiments was focused on physiological phenomena, and an attempt was made to exclude any direct psychological effects of the sugar administration. Special attention will be paid to the psychological factors in a later study.

EXPERIMENTAL

Ten healthy adult males were used throughout the 9-day study. Seven of the subjects were Air Force volunteers whose mean age was 21 years. The remaining three subjects were civilian field investigators: 33, 35, and 40 years of age. The subjects' weights ranged from 140 pounds to 220 pounds.

The subjects were restricted to an undeveloped and deserted area near the boundary of the Air Base. The camp was located in a clearing in a willow thicket at the edge of a frozen river which could be crossed on foot. On the near side of the river, the camp was separated from the populated portion of the base by a large tract of unoccupied land under laboratory control. This land was partly wooded and the remainder was an old overgrown clearing. It was the source of most of the firewood cut by the subjects. Situated in the center of this area was a large, unused, but heated building in which blood samples were drawn, nude weights obtained; and in which the subjects were allowed to remain, under supervision, for a total of not more than 2 hours per day. On the far side of the river, two seldom used roads traversed a large, flat, wild area of stunted spruces, alders, and a few large dead trees. The bedding and some of the firewood were obtained here. The roads were used for hikes. One road led to a hill about a mile from camp on which a ski slope was maintained. This slope was used for exercise and recreation on a number of occasions.

Contacts with the outside world were extremely limited. The men saw the laboratory technicians and other test personnel briefly each morning; a party of two skiers passed within 100 yards of camp on one occasion; perhaps half a dozen trucks passed hiking parties at one time or another; the camp was visited briefly by several officers from the laboratory and by a photographer; and, finally, the subjects encountered other skiers a few times on the ski slope. On the latter occasions, the subjects remained apart, chiefly because of self-consciousness fostered by their unkempt appearance. The men were required to remain in groups at all times in the company of one of the subject-investigators. They were not permitted to cross certain well-defined boundaries.

The subjects wore standard Air Force arctic clothing during the daytime, and slept in double sleeping bags on spruce bough beds at night. Due to the combined effects of a seasonal cold snap and the location of the camp in a cold sink, the degree of cold exposure was considerably greater than had been anticipated (table 1). The men were required to remain outdoors for at least 6 hours per day. During much of this time they were performing chores or taking exercise, but part of the time they spent around the fire, preparing meals, tea, or just talking. Since the wide-open assembly area was impossible to heat, and since, in an extremely cold environment, heavily clothed men derive little benefit from the radiant heat of a small stove or fire unless reflectors are used, the fire had a negligible effect on the degree of cold exposure. Thus, on the coldest days it was necessary to exercise periodically by splitting wood, hiking, etc., in order to generate enough body heat to maintain thermal balance.

Because of the excellent thermal properties of the snow caves

TABLE 1

TEMPERATURES* RECORDED DURING THE FIELD PHASE

Day	Temperature in Degrees F.
1	+14
2	0
3	-7
4	-49
5	-55
6	-42
7	-10
8	+7
9	+13

*Unofficial morning temperatures recorded at the campsite. These were not necessarily either the maximum or the minimum temperature of each day.

which were used as shelters, little if any cold stress was experienced at night. The caves were essentially hollowed-out piles of snow resting on bare ground; that is, with dirt floors. The inside cavities averaged about 8 feet in diameter, between 4 and 5 feet in height, and accommodated 2 persons. The interiors were insulated by roughly a foot of snow overhead and up to 3 feet of snow at the base, and were heated by a combination of the (relatively) warm earth, the metabolism of the occupants, and

TABLE 2

INTERIOR AND OUTSIDE AIR TEMPERATURES OF OCCUPIED SNOW SHELTER

Outside	Inside	Conditions
+4	+8	No door, unoccupied several hours
-2	+7	No door, unoccupied several hours
-7	+14	Canvas door, unoccupied, no heat
	Door in place in all following measurements	
-14	+21	Unoccupied 2 hrs., one candle.
-14	+24	After ½ hr., occupancy + second candle
-2	+21	Occupied all night, no heat
-49.5	+20	One occupant, no heat
-28	+14	Several hours unoccupied
-48	+23.5	Two occupants, 2 candles for 15 min.
-55	+19	Two occupants, overnight, no heat
-38	+14	No occupants, no heat
-42	+18	No occupants, one candle
-10	+19	Morning, no heat
-1	+15	Unoccupied
-3	+24	2 candles + 15 min. occupancy
+7	+19	Unoccupied, no heat
+10	+18*	" " " "

*Door fitted badly toward last; whole structure settling somewhat.

by candles. It will be seen in table 2 that the contributions of the three heat sources ranked in that order, with the candles exerting only a very slight effect. The clothing and bedding of the subjects were more than adequate for the inside temperatures. and none of the men experienced discomfort at night due to cold.

During the study every effort was made to simulate the degree of activity which might be expected during static survival. The men built their own snow caves, which they occupied in pairs as sleeping quarters. They also built a large community gathering place. This consisted of a square depression about 15 feet on each side, dug down to ground level, and surrounded by snow block walls about 5 feet high. It was partially roofed over with a parachute. Neither this shelter nor the fires, which were kept burning all day, had any measurable effect on the environmental temperature of the subjects but they did contribute to group morale. The subjects built these structures while subsisting on the test rations, utilizing the type of tools which might be expected to be available to survivors. They cut spruce boughs for bedding and chopped up standing or fallen deadwood for fuel, using hatchets. This was a major daily chore since they provided all their drinking water by melting snow. This usually required a hot fire for 2 or 3 hours. The fire was then kept going for the rest of the day, partly for brewing tea or cooking, but mostly for cheerfulness. In the course of gathering wood, etc., a great many snowshoe and ski trips were made over deep, soft snow for distances ranging up to 1 mile, round trip. In addition, the men were taught the elements of skiing and several cross-country ski trips of a mile or two were organized, and a small amount of downhill skiing was performed.

There were many short hikes along cleared roads. As mentioned above, the purpose of most of these trips was to generate heat.

Each man received a ration containing 1000 calories of food energy per day. The ration was issued in the form of 5 ounces of pemmican (Quartermaster Meat Food Product Bar) and opaque gelatin capsules. The capsules of half of the men (the pemmican group) contained a total of one additional ounce of pemmican; those of the other half (the pemmican-sugar group) contained a total of 40 grams of sugar. The recipient of each box of capsules was designated by a disinterested person not connected with the study who had originally assigned the subjects to the groups in a random fashion. While the subjects knew that two rations were being tested, neither they nor any of the investigators connected with the study knew the identity of the men receiving the sugar. This was done in an attempt to confine the study to objectively measurable physiological changes. In particular, it was desired to avoid dividing the subjects into privileged and underprivileged groups. For this same reason, the three field investigators shared the life of the rest of the subjects in every detail.

Since the primary purpose of the sugar supplement was to maintain the blood-sugar level within normal limits with the smallest possible dilution of the high caloric density of pemmican, it was decided to spread out the sugar intake over the whole day. Therefore, a rigid schedule was set up for the ingestion of the capsules. Each man divided his day's supply into equal doses. One of these doses was taken on the hour, every waking hour of the day. It was felt that this procedure would have the advantage of smoothing out the blood-sugar curves and preventing large fluctuations in level which might have been expected had the subjects, while in a semi-starving condition, taken larger doses of sugar at widely separated intervals. One of the rules of the camp was that the men were to travel or work in groups at all times, thus making adherence to the schedule a group responsibility.

No schedule was prescribed for the eating of the pemmican. Most of the men ate their pemmican at regular mealtimes, but some tended to postpone or do without breakfast and others, while saving a sizable portion for supper, which was usually cooked, found it desirable to nibble at the cold bar throughout the day. It may be well to note that morale was high and that the men remained cooperative throughout the study. Although the pemmican was eaten with little relish and sometimes even with distaste, particularly from about the third through the fifth day, all but a very little of it was eaten. The rejected portions were saved and weighed.

We believe that the excellent attitude of the subjects was due to a combination of factors: They received a thorough briefing on the problems of survival, including accounts of some of the more dramatic recorded incidents; their lot was shared in every detail by the investigators and they had essentially no contact with complacent and well-fed outsiders; they were not asked how they liked the taste of the ration, and it was made perfectly clear to them that they were expected to eat it whether they liked it or not; at the same time, they could see that others were eating it with benefit. We have found this blend of explanation, example, and mild coercion extremely effective in handling subjects (22). Moreover, this technique should come naturally to the commander of a well disciplined aircrew once he realizes that survivors "eat to live" and not vice versa, and that a survival ration may well be regarded as medicine.

A control period of 2 days established the levels of fasting blood sugar and urinary ketone body excretions and accustomed the men to the experimental procedures. During this time, the men lived in a room set aside as a barracks in the laboratory and subsisted at the hospital mess. Throughout the entire study 24-hour collections of urine were made and fasting blood sugars were determined daily by a modification of the method of Folin-Wu. Twenty-four hour excretions of nitrogen were determined by the microkjeldahl method and ketone body excretion was determined by converting the ketones to acetone by autoclaving according to the method of Michaels et al. (11), followed by steam distillation and subsequent determination of acetone by a modification of Frommer's test. Blood samples were collected and daily fasting nude weights were obtained indoors.

RESULTS AND DISCUSSION

From a practical standpoint, pemmican with or without sugar was found to be an excellent survival ration, as defined above. All subjects completed the field study without difficulty. Morale was high and the physical performance of the men was entirely satisfactory, considering the caloric restriction. Although the laboratory studies brought out several significant differences between the two regimens on the physiological level, there were no easily discernible differences in the performances and subjective feelings of the two groups.

Consumption of the Ration

The ration of the subjects in the pemmican group was 168 grams per day totaling 1512 grams for the 9-day study. The pemmican allowance of the pemmican-sugar subjects was 140 grams per day or 1260 grams for the whole study. The actual intakes are shown in table 3. It is readily apparent that there was no serious failure on the part of the subjects to eat approximately as much ration as was offered, although several were unable to eat all of their daily rations for a short period due to mild sensations of nausea. This difficulty was experienced only in the early part of the study. After the fifth day, nausea disappeared and food refusals ceased. This is especially important in view of the fact that the most vigorous opposition to the use of pemmican (6) was based on experiments which lasted only 3 days. Although table 3 contains little more than a hint of it, we found ample other evidence that there is a subjective adaptation to a pemmican diet. This occurs during the first 5 days and ties in with the laboratory findings reported below.

General Effects

All the subjects ate their rations with enthusiasm the first day. The portions saved for supper were stewed, fried, or made into soup, and many expressed the belief that the study would not be bad at all. The day had been spent in vigorous activity building the snow houses. The men felt somewhat more tired than usual, and a few reported momentary faintness or dizziness on standing up suddenly. This, of course, is a common symptom of starvation (8). It was a fairly frequent occurrence during the first 2 or 3 days, after which it disappeared.

TABLE 3

FOOD CONSUMPTION AND WEIGHT CHANGES OF THE EXPERIMENTAL SUBJECTS

Subject Number	*Daily Consumption of Pemmican (gm.) Day of Study									Total Food Consumption			Mean Daily Caloric Intake	Total Weight Change (lb.)
	1	2	3	4	5	6	7	8	9	Pemmican (gm.)	Sugar (gm.)	Calories		
1	168	168	168	168	168	168	168	168	168	1512	0	8845	983	-10.25
2	168	168	156	168	84	168	168	168	168	1416	0	8284	920	-12.25
3	168	142	168	168	168	168	168	168	168	1486	0	8693	966	-11.50
4	168	126	168	168	168	168	168	168	168	1470	0	8600	956	-6.00
7	168	168	168	168	168	168**	140	168	168	1484	0	8447	966	-12.50
5	140	140	72	140	140	140	140	140	140	1192	360	8773	875	-9.50
6	140	140	140	140	140	140	140	140	140	1260	360	9171	1019	-11.25
8	140	140	140	140	140	140	140	140	140	1260	360	9171	1019	-12.50
9	140	140	65	56	56	140	140	140	140	1017	360	7749	861	-9.25
10	140	140	140	140	140	140	140	140	140	1260	360	9171	1019	-9.75

*Reduced intakes due to refusals are underlined.

**The reduction in this case was due to loss of the capsules and does not represent a refusal of pemmican as such.

On the second day the men were noticeably quieter in the morning. Most of the day was spent in enlarging the cavities of the snow houses, bringing in more spruce boughs, and, in general, improving the living quarters. The first dissatisfaction with pemmican was expressed at the evening meal, and although only two men were unable to finish their allotment, no one particularly enjoyed eating his share.

Starting on this day, and on the third and fourth days, all the men had occasional, very mild sensations of nausea. These sensations came and went like hunger pains, which they probably represented. They seemed to occur more frequently before meals and they were most common before breakfast. It is obvious that if these manifestations of hunger happened to occur at the beginning of a meal, they would come to be associated with the contents of the meal. However, they were invariably absent for some time after eating, and none of our subjects felt that the pemmican was disagreeing with him or making him sick. Therefore, we attribute these symptoms to the severe caloric restriction rather than to the specific composition of the rations.

Beginning with the third day, by which time the camp facilities and routine were well established, much time each day was devoted to organized activities such as skiing, hiking, and snowshoeing. On this day, aversion to pemmican reached its peak. The men were now all agreed that it was best to eat the bar dry and cold, with as little attention as possible. During the first 2 days, coffee had been the most popular beverage, but beginning at about this time it began to taste unpleasantly strong to most men, and without exception the subjects switched to tea, which they drank more for its warmth than for its taste.

The fourth day was exciting for most of the men. They came out of their warm snow houses to find that the outside temperature had fallen to -49° F. They found that they could accomplish their chores of gathering wood and melting snow for water successfully at this temperature and that they were able to keep warm enough by relatively mild exercise. They found it easier to eat the pemmican. For the first time, they began to feel that survival was really possible under arctic conditions. Most of them lost a fear of the arctic winter of which they had been only partly conscious. Again and again, during the remainder of the study, the men expressed personal satisfaction with their accomplishments and their new-found self-confidence.

The general feeling that this represented a turning point was confirmed and reinforced on the fifth day, which was even colder (-55° F.). The pemmican was going down much more easily and all symptoms of nausea had ceased. From this time on there were no major changes in activities, behavior, or subjective feelings. None of the subjects redeveloped a liking for pemmican during the course of the study, but they ate it with no difficulties other than a reluctance to begin at breakfast time. As a rule it tasted better than anticipated, and there was little trouble in finishing it. As the study wore on, many of the subjects voluntarily stated that they would like to have more pemmican. On the seventh day, subject No. 9, who had had the most difficulty in eating his allotment from the third to the fifth day (see table 3), asked if he could have returned to him the uneaten portions which he had rejected earlier in the study. The general feeling was that pemmican was a necessary evil, like insulin to a diabetic. You would have preferred something else, but nothing else was available. It made you feel better, so you ate it.

<u>Physical Endurance</u>

As time went on, the men became weaker and tired more readily. A typical sight was two men slowly plodding along, laboriously dragging a small tree branch which either of them could have picked up and carried with ease on the first day. Generally while seated the subjects felt relaxed, comfortable, free from hunger pains or unpleasant symptoms of any kind, disinclined to exert themselves but not particularly tired. As a matter of fact, most of them thought that they felt remarkably well. Once started on a slow hike, they felt slightly tired but capable of going on indefinitely. However, any exertion greater than walking on a hard, level road very rapidly led to exhaustion. On resting, recovery was rapid and complete, although only temporary. The result was that it took a long time to accomplish any task. In the sense that the cycle of exhaustion and recovery could be repeated indefinitely with no apparent cumulative effect, endurance was good; certainly adequate for static survival and probably for slow travel, even over rough terrain. We have no reason to believe that this slowly increasing weakness was due to anything other than general starvation such as would occur on any 1000 calorie diet.

During the course of the study, several of the men suffered from mild upper respiratory infections, and one man (subject No. 8) had rather severe diarrhea on the third day only. We do not feel that any of these disturbances were brought about or aggravated by the survival conditions or by the ration.

Fluid Balance

Weight changes are given in table 3. It is apparent that a substantial part of these losses must be ascribed to dehydration, since the average total decrease of 10.5 pounds, or over one pound per day, is much too great to be accounted for by the caloric deficit. Energy expenditure was high only in the first few days of the study when the camp was being set up. As increasing weakness forced the men to slow down, it undoubtedly dropped well below normal for outdoor life. In our estimation, taking the entire study into consideration, the average daily expenditure could not have exceeded 3000 calories. Since the ration furnished 1000 calories, this would have left a deficit of 2000 calories. Study of the nitrogen balances indicates that only about 140 calories per day could have been derived from net protein catabolism. The remainder could have come only from fat and would account for the loss of not more than one-half pound per day. Moreover, the pattern of the weight losses is very suggestive. Thus there was a large initial loss in weight when the men were placed on the restricted diet, following which the daily losses became stabilized. The recovery period after termination of the study was characterized by a sharp initial gain in weight, tapering off after the first 2 or 3 days. Although this is indirect evidence of changes in water balance, it seems to confirm the observation of Consolazio and Forbes (1), who observed a high retention of water and a sharp increase in body weight during early recovery.

It should be emphasized that this dehydration was due entirely to physiological causes. Ample water was available at all times for drinking, and water intake was completely unrestricted. Thirst was never present. As a matter of fact, all the subjects felt that swallowing the large number of gelatin capsules required more water than they cared to drink. Although fluid consumption was not measured, urine volumes fell to very low levels after the first few days (table 4), indicating a corresponding drop in intake. A universal and striking accompaniment of the recovery period was a pronounced thirst during the first day or two following resumption of normal eating habits.

The causes of these changes in fluid balance are unknown, but they appear to be related to the caloric intake and not to the specific composition of the diet (2). A large initial loss in weight at the beginning of any reducing regimen and a discouraging jump in weight immediately after abandonment of the diet are the invariable experiences of the chronic dieter. If the weight curves of the subjects in Sargent's monumental study (15) are plotted, it will be seen that this same pattern of weight loss was obtained with all the diets tested at the 1000 calorie level (2). We can see no reason why this type of dehydration, per se, should be detrimental to health or performance.

Fasting Blood Sugar

Table 5 shows the daily fasting blood-sugar values for all sub-

TABLE 4

URINE VOLUME
(ml)

Day	Subject	Pemmican				Average	Pemmican + Sugar					Average
		1	2	3	4	7		5	6	8	9	10	
1		870	934	1090	854	532	856	1160	1534	882	-	-	1193
2		1224*	834	1382	1114	570	1025	884	1610	974	980	1190	1148
3		870	1260	1890	2424	1294	1548	1722	2530	1410	870	770	1460
4		1036	2240	1430	2680	896	1656	1724	2240	1758	922	1324	1594
5		950	1466	1922	2624	1230	1638	1284	1876	2100	954	1730	1589
6		840	1130	1578	1742	768	1212	1194	2074	1728	800	1242	1408
7		768	1136	1604	974	910	1078	900	1740	1276	958	1120	1199
8		718	1044	1590	1090	942	1077	588	1580	1660	670	985	1097
9		735	1380	1055	2480	260	1182	885	1680	1300	680	820	1073
10		700	1340	840	1815	475	1034	1330	1795	1095	780	840	1168
11		745	1150	1100	1685	620	1060	795	1340	1000	715	665	903

*Maximum daily volumes are underlined.

TABLE 5

EFFECT OF SUGAR SUPPLEMENT UPON FASTING BLOOD SUGARS

	Pemmican (Meat Food Bar)					Pemmican + Sugar				
	Subject									
Day	1	2	3	4	7	5	6	8	9	10
1	58.4	77.3	79.7	59.2	81.9	75.0	77.0	68.1	59.2	63.2
2	53.7	66.3	59.2	52.9	70.3	59.2	74.2	43.3	63.2	61.6
3	67.2	72.0	65.6	59.2	60.8	76.8	79.2	80.8	74.4	65.6
4	61.6	67.2	60.0	62.4	52.0	63.2	79.2	61.6	60.8	64.0
5	67.0	77.1	62.0	61.9	65.0	69.7	77.8	62.7	63.1	62.8
6	60.0	77.2	60.1	58.1	48.6	63.3	78.8	72.0	64.8	60.4
7	60.8	68.2	56.7	57.5	56.7	69.0	83.0	69.0	60.8	63.3
8	63.9	74.0	62.3	60.0	62.3	64.7	72.5	80.3	63.9	62.3
9	62.6	74.9	61.9	60.3	53.6	65.5	81.2	81.7	53.8	68.6
Means	61.7	72.7	63.1	59.1	61.2	67.4	78.1	68.8	62.7	63.5
Pre-treat-ment Means	84.6	109.8	88.5	85.4	95.4	95.4	94.4	86.3	80.2	87.8

Analysis of variance of mean fasting blood sugar values following their adjustment for regression upon mean pre-treatment values.

Source	df	Adjusted Mean Square	F
Subjects treated alike	7**	16.26	
Treatments	1	109.96	6.76*
Total	8**		

*$.01 < p < .05$

**Reduced by 1 df for regression coefficient ($b = .4580$; $r_{xy} = .73$)

jects. This table also presents the results of an analysis of variance of the blood sugars, wherein these values were adjusted with regard to the regression of the post-treatment levels on the control levels. During the field study, the fasting blood-sugar values for the subjects who received the dietary sugar were significantly higher (at the .05 level of confidence) than those of men receiving pemmican only. No subjective differences were noted between the two groups which could be attributed to this difference in blood-sugar levels.

Nitrogen Balance

Table 6 shows the daily nitrogen balances of the subjects. There is considerable overlapping of values between the two groups, mainly because of the gradual return toward normal of the balances of both groups. Considering the whole 9-day period, there are no significant differences between the nitrogen balances of the subjects receiving pemmican with sugar as against those receiving no sugar. The dietary sugar, therefore, had little if any effect on the nitrogen balance.

Ketosis

Daily ketone body excretions, measured as acetone, are shown in table 7. The analysis of this material has given us considerable difficulty. A cursory examination of the data reveals that the figures for subject No. 8 are exceptionally high. In fact, his total excretion for the entire field study was 2 to 5 times that of any other subject in either group. Disregarding this subject, the ketone

TABLE 6

EFFECT OF SUGAR SUPPLEMENT UPON DAILY NITROGEN BALANCES
(grams)

	Pemmican					Subject	Pemmican + Sugar				
Day	1	2	3	4	7		5	6	8	9	10
1	-6.4	-7.2	+2.1	-3.5	-8.3		-0.4	-11.2	-11.6	-9.2	-2.9
2	-11.2	-7.4	-5.1	-6.5	-4.2		-5.8	-10.6	-9.2	-12.6	-11.5
3	-12.4	-9.9	-5.2	-7.5	-10.3		-12.6	-8.7	-14.8	-14.3	-7.6
4	-6.0	-4.7	-4.4	-8.1	+1.1		-4.1	-7.2	-10.0	-9.6	-6.6
5	-3.8	-7.0	-5.8	-5.3	+1.3		-1.4	-4.9	-5.0	-6.9	-3.1
6	-4.2	-2.7	-5.9	-3.6	+1.1		-1.4	-4.9	-6.3	-2.8	-4.4
7	-4.5	-3.4	-6.1	-4.3	-		-1.3	-5.5	-9.6	-4.1	-4.4
8	-5.4	-3.9	+0.3	-5.5	+5.8		-4.8	-5.4	-8.5	-5.4	-5.1
9	-5.8	-2.0	-2.5	-6.7	+4.4		-3.7	-5.4	-8.3	-2.5	-3.8
Total	-59.7	-48.2	-32.6	-51.0	-5.8		-35.5	-63.8	-83.3	-67.4	-49.4

Analysis of variance of 9-day total nitrogen balances

Source	df	Mean Square	F	p
Between diets	1	1042.44	2.67	ns
Error	8	390.49		
Total	9			

body excretion of the pemmican group seems to be considerably larger than that of the pemmican-sugar group, although there is some overlapping of values. A more rigorous analysis confirms these impressions. Without subject 8, the difference between the two groups is signifi-

TABLE 7

EFFECT OF SUGAR SUPPLEMENT UPON 24-HOUR KETONE BODY EXCRETION
(grams acetone)

	Pemmican					Pemmican + Sugar				
	Subject									
Day	1	2	3	4	7	5	6	8	9	10
1	0.49	0.19	0.14	0.54	0.46	0.15	0.27	1.06	0.19	0.97
2	1.37	1.21	0.95	1.60	0.91	0.57	0.74	4.83	0.47	1.75
3	2.27	2.27	2.13	2.20	2.56	1.31	0.67	6.96	1.00	2.73
4	1.76	1.87	1.42	1.78	1.86	0.83	0.79	4.82	0.97	2.14
5	1.35	2.16	1.44	1.44	1.99	0.68	0.81	3.12	1.18	1.68
6	1.04	1.89	1.07	1.27	2.56	0.58	0.71	3.07	0.62	1.52
7	1.07	2.54	0.51	2.08	1.80	0.72	0.66	3.51	0.58	1.14
8	0.87	2.06	0.41	1.50	1.09	0.71	0.63	2.23	0.54	1.09
9	0.50	1.19	0.27	0.90	1.31	0.37	0.45	1.56	0.32	0.53
Totals	10.71	15.39	8.34	13.31	14.54	5.92	5.73	31.16	5.87	13.55

Analysis of Variance of 9-day Total Ketone Body Excretion

Source	df	Mean Square	F
With Subject 8			
Diet	1	2.46	<1
Error	8	64.77	
Total	9		
Without Subject 8			
Diet	1	48.39	4.34*
Error	7	11.15	
Total	8		

*$.05 < p < .10$

cant at a level between .05 and 0.1; with subject 8, there is no significant **difference** between the groups. When subject 8 was retested on the same diet several months later, his acetone production was within the "normal" range of the diet. Moreover, he participated in another similar study under strictly comparable conditions the following winter, at which time his ketone excretion picture agreed with that of his group. At no time have any of his other physiological reactions departed from the norm. The only possible clue to his behavior in the experiment was the attack of diarrhea which he suffered on the third day, and we have no proof whatever that the two phenomena were causally connected. Nevertheless, we have concluded that carbohydrate, at the low level employed in this experiment, does significantly depress ketosis in most individuals on a high-fat, low-calorie diet. Apparently it is possible, under certain as yet unknown circumstances, for normal individuals to show a temporarily elevated response to ketogenic stresses.

Two other conclusions can be drawn from the data presented in table 7. First, the excretion of ketone bodies in the most extreme case (7 grams on the third day by subject 8) is still too small to produce deleterious effects of any appreciable magnitude. Second, there is a marked adaptation to the ketogenic diet. In most cases, the excretion of ketones was negligible by the last day. The day to day variation is presented graphically in figure I. It should be noted in passing that our control values are somewhat higher than the usually reported figures. This is due to our use of an improved, quantitative method which accounts for β-hydroxybutyrate as well as

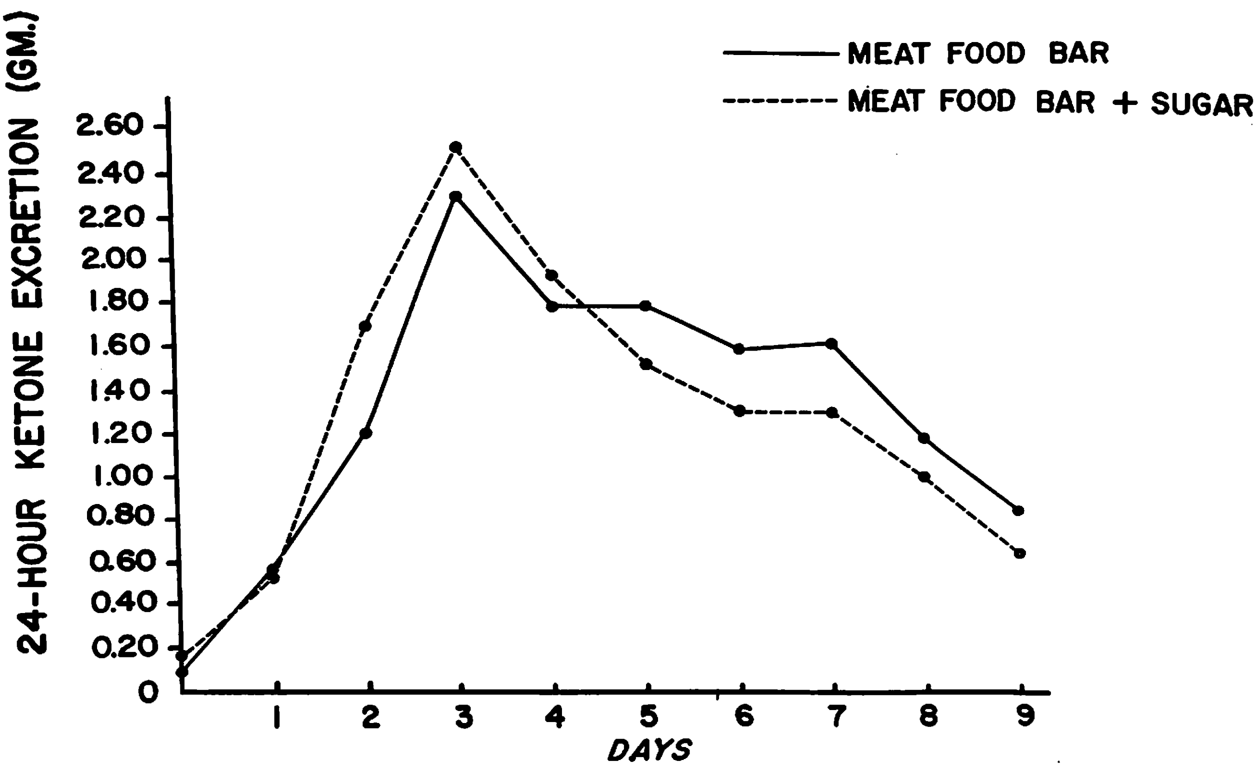

Figure I. Urinary ketone excretions during the 9-day field study

for acetoacetate and acetone. In the past, most investigators have employed the Rothera reaction which is far more sensitive to aceto-acetate than to acetone, and which misses the β-hydroxybutyrate completely.

Practical Implications

The bulk of the evidence presented above indicates that a survivor receiving a small sugar supplement will be better off than one subsisting on pemmican alone. From a purely objective standpoint, however, the difference will be slight, and the most important conclusion to be drawn from this work is that pemmican, with or without sugar supplementation, constitutes a physiologically acceptable solution to the logistic problem of the Arctic Survival Ration.

Metabolic Adaptation

Of potentially greater significance than the immediately applicable information just presented, are the sequential changes which have been mentioned briefly in the foregoing paragraphs. These indicate that there is an adaptation to a high-fat, high-protein, low-carbohydrate, low-calorie diet. Thus, while the fasting blood sugar levels (percentage of controls) dropped sharply at the beginning of the period of restricted carbohydrate intake, they quickly leveled off and perhaps even showed some tendency to rise again (figure II)

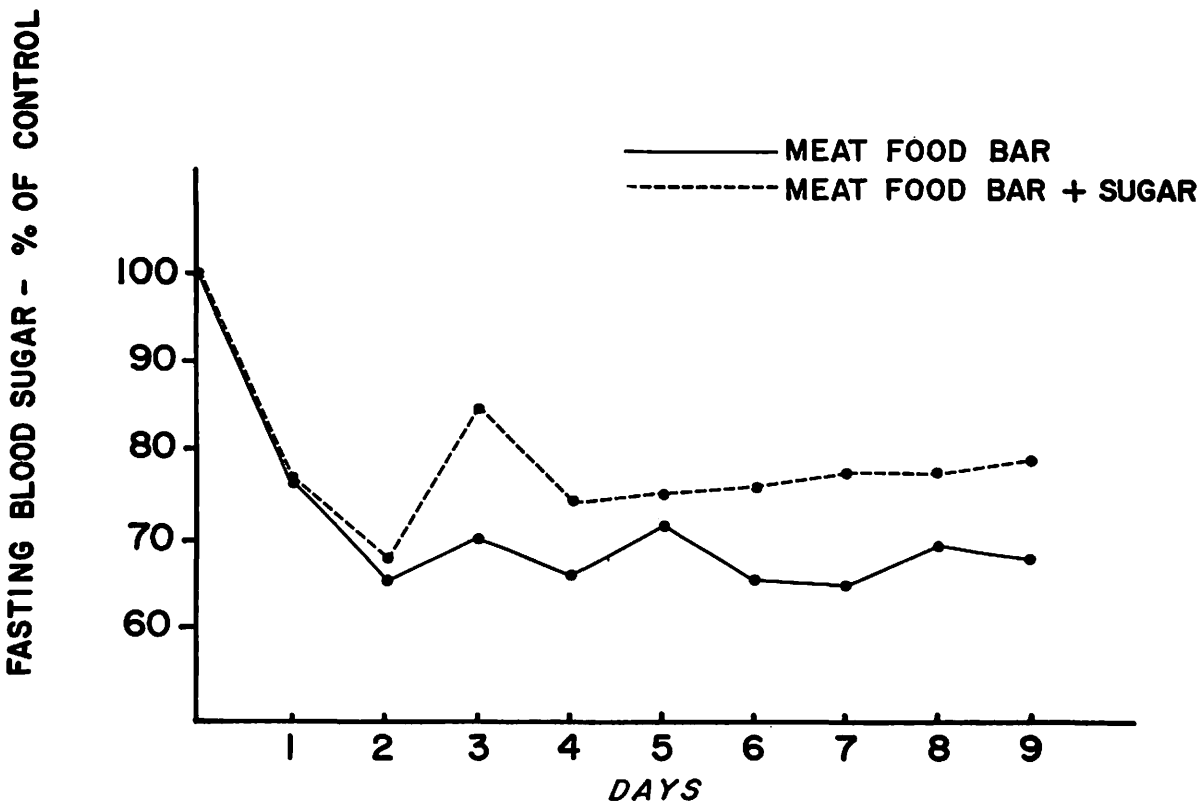

Figure II. Fasting blood sugar levels during the 9-day field study even though there was no increase in the availability of carbohydrate. The initial drop can be explained as an indication of the depletion of liver glycogen, but why is this fall arrested? It is true that some of the amino acids and the glycerol derived from fat metabolism are glycogenic, but these potential sources of carbohydrate intermediates would not be capable of supplying the quantity of glucose metabolized by the normal, well-fed man. Apparently, the requirement is much reduced during semi-starvation--a possible explanation of the significant increase in blood sugar levels brought about by the ingestion of a mere 40 grams per day.

The curve of daily nitrogen balances (figure III) follows a

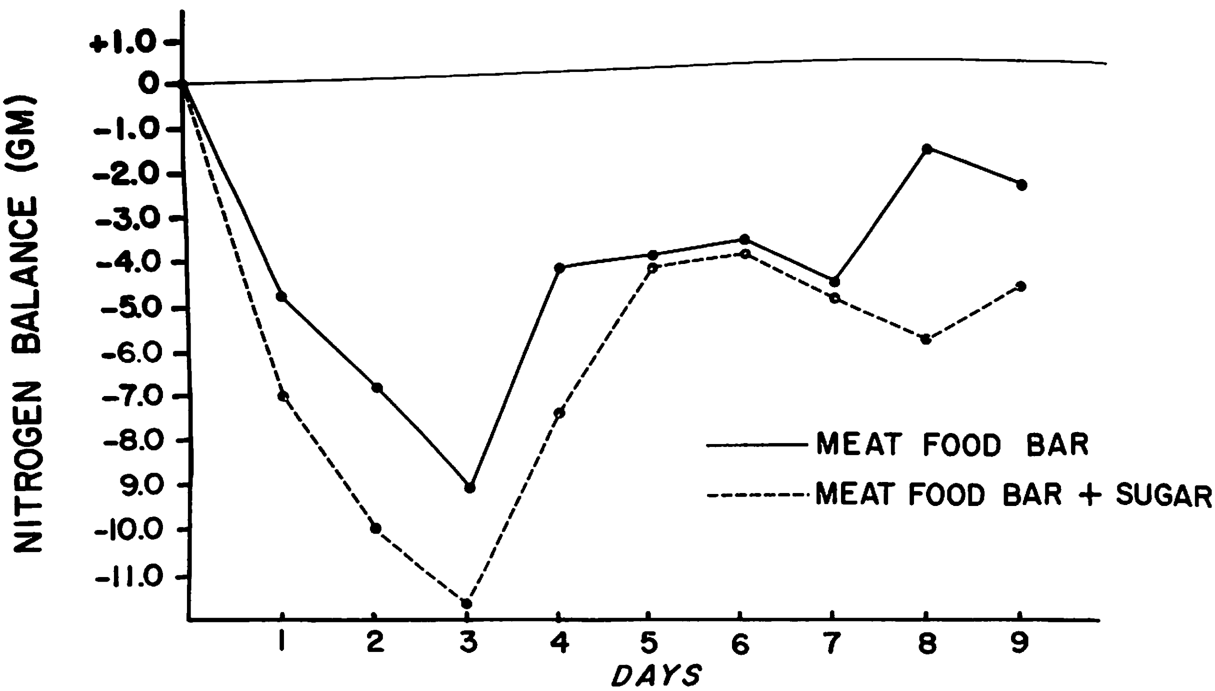

Figure III. Nitrogen balances during the 9-day field study similar pattern. On the third day of the study, the nitrogen metabolism reached a maximum. Following this, it dropped rapidly until the fifth day. From then until the end of the study, nitrogen metabolism followed no well defined pattern, although there was a tendency for the mean daily balances of the men receiving sugar to be somewhat lower than those of the men receiving pemmican alone.

The excretion of ketones, as shown in figure I, reached a peak on about the third day of the experiment, after which it fell steadily, with the values approaching the range for normal urine by the ninth day. This phenomenon shows some similarity to the results cited by Sargent (16) i.e., a transitory rise in ketone excretion. In our studies, however, there was a caloric deficit throughout the experiment. The curve which we obtained cannot be explained on the basis of changes in the level of physical activity of the subjects, since we have repeatedly obeained the same picture in subjects engaged in sedentary activity within the laboratory.

It is evident from the foregoing that the mechanism of intermediary metabolism must undergo modifications during the first few days of subsistence on a low-carbohydrate diet. It has been observed that a diet high in fat and low in carbohydrate results in depressed utilization of glucose in man (5, 19) and animals (3) as reflected in reduced tolerance to oral or intravenous glucose. A diminished carbohydrate utilization following a fast has also been reported in humans (10). The fact that in spite of the low sugar intake, the blood glucose levels of the men receiving sugar in the current study were elevated above those of the men receiving pemmican alone, seems to bear out these observations. The percentage of the total calories which was supplied by sugar (endogenous as well as exogenous) was probably too small to interfere materially with the trend toward adaptation to a fat and protein diet.

There is also some evidence that animals may become adapted to a high-fat diet and to caloric restriction. The nitrogen balance shows a tendency to approach equilibrium (18) and animals are able to maintain their weight with fewer calories if given a high-fat diet (7). Substitution of fat for carbohydrate has been shown to cause only a transitory increase in nitrogen excretion (21). Turning to *in vitro* studies, Whitney and Roberts (24) have observed depressed glycogenesis and fatty acid synthesis in animals fed a high-fat diet, while Tepperman et al.(20) observed increased oxidation of palmitic acid in high-fat-fed rats. Roberts and Samuels (14) observed an upswing in the blood-sugar curve in animals after a 3-day fast. Their experiments also indicated that the feeding of a high-fat diet prior to fasting was followed by a sparing of carbohydrate and protein during the fasting period.

Tentative Account of Adaptive Process

We visualize the sequence of events during the period of dietary adaptation as follows:

1. When the total caloric intake of a well-fed normal individual is suddenly reduced to a level below metabolic requirements, the first deficiency to make itself felt is that of energy. Regardless of the composition of the remaining food, the body draws heavily on all of its energy stores--carbohydrate, protein, and fat--seemingly without

preference. In the first few days, the composition of the fuel mixture actually burned depends principally on the relative total availabilities of the several types of foodstuffs, without distinction between stored and ingested forms and uncomplicated by requirements for specific nutrients.

2. Because the carbohydrate reserves are the most limited, they are exhausted first. This is followed by a sharp drop in the blood glucose levels. Since this drop is due entirely to the energy deficit and not to a specific "carbohydrate hunger," no increase in the proportion of sugar in the ration can prevent a fall in blood sugar at the beginning of any period of substantial caloric restriction.

3. Whether protein is stored, in the strict sense, as an inert reserve material or whether a portion of the active metabolic machinery is "expendable," it is clear that a rather large amount of tissue protein can be burned for fuel without serious results. Thus, at the beginning of the period of caloric restriction, the nitrogen balance becomes strongly negative, dropping still farther after exhaustion of the glycogen stores. Within 5 days the fall is arrested and the balance improves, although it does not return to normal, even with a very high protein intake, as long as the energy balance remains this negative. The reduction in nitrogen metabolism probably results chiefly from depletion of the "dispensable protein" although it may be partly a reflection of more efficient fat utilization.

4. Quantitatively, fat is by far the most important source of energy during starvation, and after the early exhaustion of the available carbohydrate and protein, the body becomes almost completely

dependent upon its fat reserves for energy production. However, the metabolic apparatus of an individual who has been subsisting on the usual mixed diet of our culture is not adjusted to burn fat efficiently in the absence of carbohydrate. Thus, as the preformed carbohydrate is used up, ketone bodies appear in the blood and urine.

Alterations now occur in the pathways of intermediary metabolism (possibly between the terminal stages of fatty acid oxidation and the Krebs cycle) which facilitate the complete catabolism of fat and thereby reduce ketonuria to negligible levels. Adaptation to ketogenic stimuli has been reported a number of times in the past (16), but has received very little attention, possibly because its magnitude has been obscured by failure to employ quantitative methods. Its mechanism should be susceptible to attack on the cellular and subcellular levels.

The ketosis produced in a normal, previously well-fed individual by a high-fat diet is reduced or prevented by carbohydrate ingestion. Oxalacetate, produced from glycolytic reactions and carbon dioxide fixation, maintains the citric acid cycle and thus facilitates the complete combustion of fat. However, it is unlikely that the spontaneous reduction in ketosis which occurs during continued ingestion of a ketogenic diet or during prolonged reliance on endogenous fat reserves is due to an increase in the availability of carbohydrate, as such, since it is well known that the activities of a number of glycolytic enzymes decrease markedly during subsistence on high-fat diet (9) and during fasting (23) with a sharp reduction in glucose tolerance, an actual increase in glycogen stores (4) and a rise in blood sugar (see above). If the adaptation cannot be explained on the basis of increased carbohydrate metabolism, it must be due to changes in protein or fat metabolism.

Protein is a potential source of carbohydrate intermediates capable of "sparking" the Krebs cycle and thereby facilitating the oxidation of ketone bodies. It is true that in this study the reduction of ketonuria began at the time when the nitrogen balance had started to improve, and that the reduced ketone body excretion in the last days of the study was accompanied by reduced nitrogen excretion. While this suggests that the products of protein catabolism did not play the leading role in reducing ketogenesis, the total nitrogen metabolism remained high, and it is quite possible that tracer studies would show the channeling of protein catabolism into the production of lower carbohydrate intermediates, such as pyruvate, which might then give rise to oxalacetate via the malic enzyme pathway.

Another possibility, at present admittedly unsupported by evidence, is the opening up of a pathway from acetate back to pyruvate and thence to oxalacetate by the malic enzyme route. The necessary reactions are not known to occur in animals although they have been reported in lower forms (12). In this connection, Rapport (13) finds that succinate stimulates acetate oxidation in liver homogenates from control rats, but is totally without effect in homogenates from cold-exposed, fasted rats. Rapport is inclined to believe that this may mean that "while carbohydrate metabolism is certainly essential for the optimum oxidation of fatty acids, the locus of the mechanism is not in the Krebs cycle." This, of course, is not regarded as proven and is advanced only as a suggestion, although it is an intriguing one.

SUMMARY

1. The performance of 10 subjects, living outside in a severely cold environment and subsisting on a daily intake of 1000 calories of either pemmican or pemmican-plus-sugar, was deemed adequate for most survival situations faced by aircrews in the Arctic.

2. The fasting blood sugar levels of the subjects receiving sugar were significantly higher than those of subjects receiving pemmican only.

3. The nitrogen balances of the subjects were not significantly affected by the isocaloric supplement of sugar.

4. The 24-hour ketone body excretions of the subjects receiving sugar were somewhat less than those of subjects receiving no sugar

5. Sequential changes in the negative nitrogen balances and ketone body excretions were interpreted to mean that the experimental subjects were becoming adapted to a carbohydrate-free diet and to caloric restriction.

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