GLUCOSE TOLERANCE IN ANTARCTICA

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ABSTRACT. Factors controlling blood-sugar levels are outlined briefly with particular reference to the glucose tolerance test. Morning and afternoon glucose tolerance tests were carried out in spring, summer, autumn and winter on a population of men spending up to 2 years on an Antarctic base at lat. 75° S. The seasonal and diurnal changes observed are described and discussed.

THE oral glucose tolerance test is a technique used routinely in the investigation and assessment of diabetes. This is an illness in which the body's ability to deal with ingested carbohydrate (sugars and starch) is impaired. The body's cells are unable to utilize sugar, principally glucose, in the blood stream as fuel. Blood-sugar level rises, sugar passes out in the urine and fat is used as fuel. This has various consequences from weight loss to coma and death in the more severe acute aspects of the disease.

A multiplicity of factors can affect blood sugar at any one time, but control of sugar levels is mediated principally by insulin, a hormone produced by the pancreas. This hormone is released into the blood stream in response to a rise in blood sugar and effects the passage of glucose across the cell membrane into the body of the cell where it is subsequently metabolized. In the diabetic there is a failure of the pancreas to produce enough insulin for the body's needs, either due to a failure in the production mechanism or due to the fact that the total body cell mass has become too large for the amount of insulin being produced by what would usually be considered to be a normal pancreas, i.e. in obesity.

The glucose tolerance test provides an index of the individual's ability to deal with carbohydrate in the form of glucose, a simple sugar. Various forms of the test are in use both in the clinical and the research situations. A quantity of glucose is taken orally, usually in the form of a 20–30 per cent solution, and blood-sugar levels are measured before ingesting the glucose and at intervals, usually half-hourly, for the 2–3 hr. following ingestion. The test is normally done on the fasting subject at rest, first thing in the morning, and 50 g. of glucose is the usual size of glucose load. In the young healthy subject blood-sugar levels classically follow the sort of pattern shown in Fig. 1. Blood sugar rises from the fasting level of around 60–70 mg. per cent to a peak of around 120–140 mg. per cent at 0·5 hr., falls to the 2 hr. value, often below the fasting level, then may rise again slightly at 2·5 hr.

In the diabetic glucose tolerance is impaired. The fasting level is often high and following the glucose load blood sugar may rise to very high levels, reaching its peak at 1, 1·5 or 2 hr.

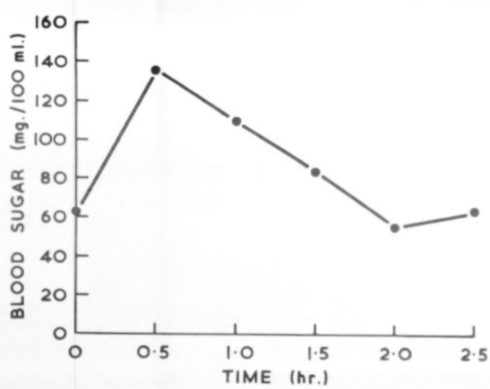

Fig. 1. Results of hypothetical "classical" glucose tolerance test done on a young healthy subject early in the morning following an overnight fast and ingestion of 50 g. of glucose.

or even later, and by 2·5 hr. is still well above the fasting level. The degree of elevation of the curve bears a direct relationship to the severity of the diabetes.

Over the years various other factors have been found to influence the shape and height of the glucose tolerance curve in the normal subject. These have been reviewed by Jarrett (1973) and include previous carbohydrate intake (restriction impairing tolerance), physical activity (inactivity impairing tolerance), size of the glucose load, length of fast and time of day, tolerance being impaired in the afternoon compared with the morning, i.e. the curve is higher and the peak later.

This latter phenomenon, a diurnal variation in glucose tolerance, was looked at more closely by Jarrett and Keen (1969, 1970). They concluded that the relative intolerance seen in an afternoon test, when compared with one in the morning, was a normal feature. However, they thought the degree of intolerance seen in the afternoon, in an otherwise normal subject, bore a direct relationship to the subsequent development of diabetes and atherosclerotic arterial disease.

In view of these findings in the normal subject, it was thought that it would be interesting to look at the diurnal patterns of glucose tolerance and their variation with the seasons in a population of healthy young men spending a year at an Antarctic station where they were subject to an unusual light/dark cycle.

The Setting

Halley Bay is a British Antarctic Survey station on the Caird Coast of the Weddell Sea, situated at lat. 75°31′S. The station itself is built on the Brunt Ice Shelf and over the years it has been covered by drift. In 1972, when this investigation was carried out, the living huts were about 10 m. underground and were accessible by shafts from the surface.

For 3 months of the year, early May to mid August, the sun is below the horizon and during November, December and January it does not set. For just 1 month at mid-winter (21 June) the darkness is virtually continuous for 24 hr. a day, although around noon and in clear weather a glow can be seen on the horizon.

Norman (1965) has defined life at Halley Bay in terms of the residents' exposure to the environment. He looked at the activity patterns of four subjects and found that in March 16 per cent of the subjects' time was spent out of doors, in June 7 per cent, September 4 per cent and December 13·5 per cent. He pointed out that in March much time was spent outside preparing for the winter and, although the sun returned in August, September is in fact the coldest month of the year with a mean temperature of −35° C. September (the spring equinox) more closely resembles the winter months than it does March when the mean temperature is −20° C.

Materials and Methods

The subjects were 12 of the men resident at Halley Bay during 1972. Average age in January 1972 was 24 yr. and average height 182 cm. Average weight in March was 73 kg., June 72 kg., September 72 kg. and December 72·5 kg. All were fit and healthy and none had a family history of diabetes.

Base experiment

Glucose tolerance tests (GTTs) were performed morning (08.00 hr.) and afternoon (16.00 hr.) as close to mid-winter, mid-summer and the two equinoxes as possible. For the morning test, subjects starved from midnight the previous day and for the afternoon test ate nothing following a light breakfast at 08.00 hr. No other specific dietary preparation was made but all subjects were on the same diet.

Subjects sat quietly during the test and did not smoke. Venous blood was taken through an indwelling cannula. After a fasting blood sample had been taken, 50 g. of D glucose was given orally dissolved in 250 ml. of water and 10 ml. of venous blood taken at 0·5, 1·0, 1·5, 2·0 and 2·5 hr.

The blood was taken into anticoagulant tubes and stored on ice until the end of the test when two 0·1 ml. aliquots were pipetted each into 1·0 ml. of 2 per cent perchloric acid and frozen for shipment to the United Kingdom for glucose estimation. The remainder of the sample was centrifuged, the supernatant plasma removed and frozen for shipment to the United Kingdom to be analysed for insulin.

Field experiment

In addition to the station programme as described, an experiment was carried out some distance from the station immediately after mid-winter. Five subjects and an observer spent a week in a hut and a tent approximately 5 km. from the station immediately after mid-winter during the period of continual darkness. Except for the observer none of them had watches. They had no way of telling the time and adopted their own sleep/activity pattern. They tended to follow a 25–26 hr. sleep/activity cycle such that at the end of a week they were getting up at 17.00 hr. and going to bed at 06.00 hr. GTTs were done on the subjects and the observer at 16.00 hr. on the fifth day for which they had to be woken up and at 08.00 hr. on the eighth day after they had been up for 12 hr. Venous blood was taken and two 0·1 ml. samples stored in 1 ml. of 2 per cent perchloric acid. It was not possible to save plasma for insulin analysis.

During the week the temperature varied between −35° and −45° C and very little outside activity was possible. Apart from a short walk of half an hour early in the week, subjects spent the time sitting, reading, talking and playing cards.

Analysis

Analysis of the samples was done in the United Kingdom between June and December 1973. The glucose analysis was done using a glucose oxidase technique on an Auto-analyser (Technicon Method 9a). Plasma insulin was measured using a double antibody immunoassay (Morgan and Lazarow, 1963).

In order to avoid interassay variation, all the samples from each subject were measured in one batch and processed in random order. A mean value was taken of duplicate samples of each specimen.

Results

For various reasons it was impractical for any of the analyses to be done in the Antarctic and a way had to be found to preserve levels of glucose in the samples until the analyses could be performed in the United Kingdom. This was done by storing the blood in 2 per cent perchloric acid. Some problems arose from this in that on analysis the figures for glucose levels were considerably lower than expected. This has been investigated and fully discussed elsewhere (Campbell and others, 1975). The reason has been shown to be a peculiarity of the glucose oxidase technique on samples stored in perchloric acid. There was no evidence that degradation of the glucose had taken place nor that the perchloric acid had inhibited the action of the glucose oxidase enzyme.

Because of the demands made on them by routine at the station, two of the subjects were unable to participate in the September tests, and due to a technical mishap the afternoon results for one subject in June were lost. Data were therefore complete on 12 subjects in March and December, 11 in June and ten in September.

Diurnal variation in glucose tolerance

Morning and afternoon GTTs done at the station on the four occasions during the year are presented in Fig. 2. Mean blood-sugar levels (±SEM) are given for all subjects on whom results are available. The characteristic difference between morning and afternoon curves is seen to persist throughout the year. However, the magnitude of the difference varied between seasons. Differences between morning and afternoon levels decreased steadily from March to September and increased again in December.

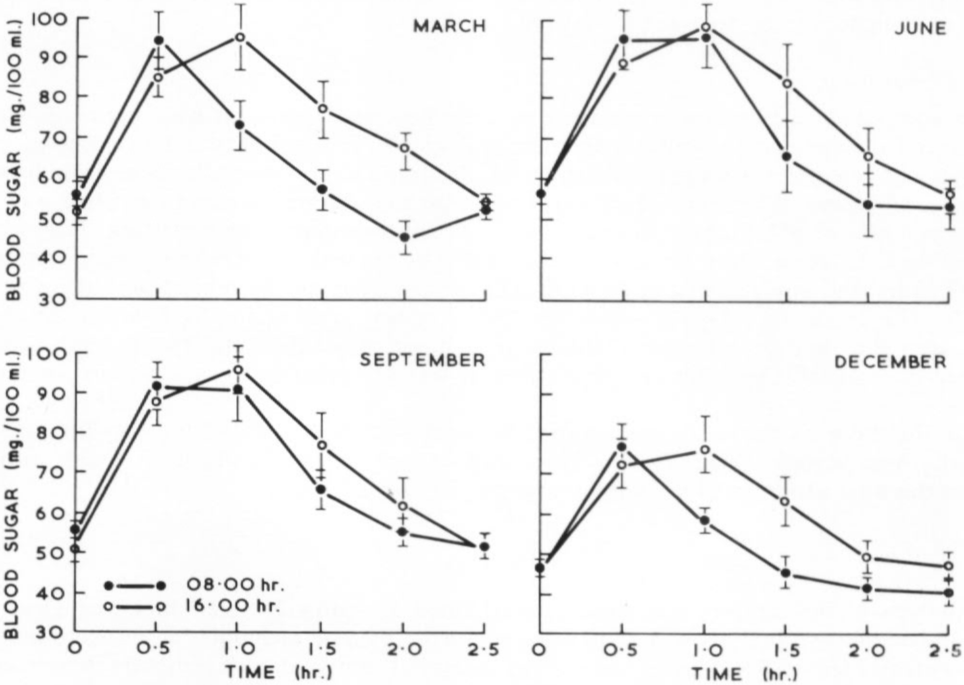

Fig. 2. Glucose tolerance tests done on all subjects at 08.00 and 16.00 hr. season by season—mean blood sugar (mg./100 ml. ± S.E.).

Seasonal variations in glucose tolerance

The mean values for all morning tests and all afternoon tests are shown in Fig. 3. December curves for both morning and afternoon are lower than at other times of the year, i.e. glucose tolerance was improved. Afternoon tests in all cases peaked at 1·0 hr. In March and December the morning peak occurred quite distinctly at 0·5 hr. but in June and September, the periods with the least amount of outside activity, the peak was delayed and appears to have occurred between 0·5 and 1·0 hr., i.e. there was a relative decrease in glucose tolerance, or the body's ability to cope with a glucose load, at these times when compared with March and December, the periods when the greatest amount of outside activity occurred.

Mean insulin levels for each time point in all the glucose tests are given in Table I along with the corresponding mean glucose levels. Results are given for morning and afternoon tests for all four seasons. The highest insulin levels and the greatest diurnal variation in insulin levels occurred in March (autumn). Subsequent tests showed a progressive decline in insulin levels both in their absolute values and in their diurnal variation.

The relationship between glucose and insulin is shown in Figs. 4 and 5. In Fig. 4 glucose and insulin levels are plotted for morning and afternoon, and the calculated regression lines

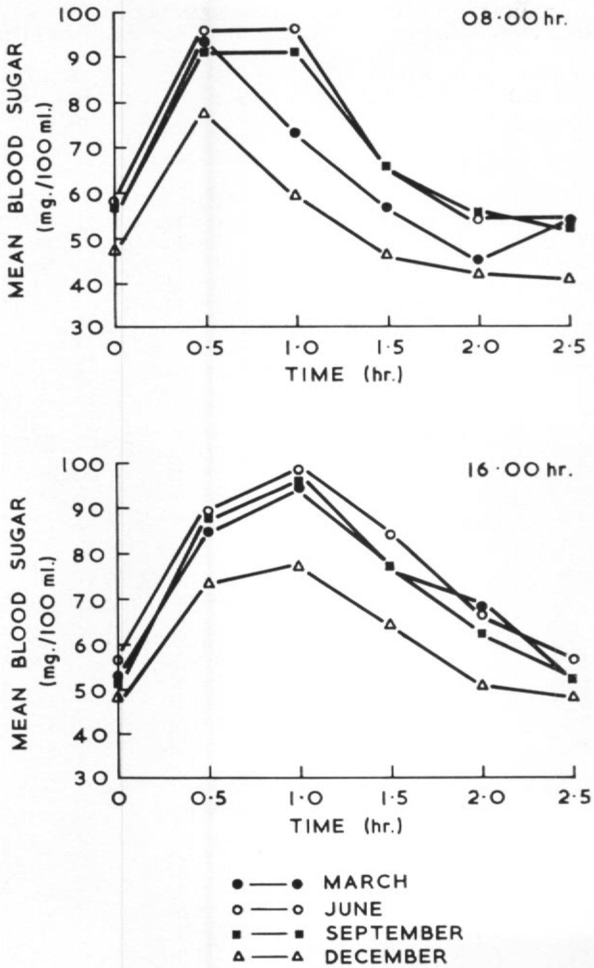

Fig. 3. Comparison of glucose tolerance tests between different times of the year, at 08.00 and 16.00 hr.

for morning and afternoon are drawn separately and presented season by season. In Fig. 5 these regression lines are drawn comparing 08.00 hr. results season by season and 16.00 hr. results season by season. In all cases the linear correlation between glucose and insulin was highly significant ($p<0\cdot001$).

In March and June the relationship between glucose and insulin can be seen to be quite different between morning and afternoon, but in September this difference seems to have virtually disappeared.

A seasonal variation in the glucose/insulin relationship as shown by the slopes of the glucose/insulin regression lines is demonstrated in Fig. 5, the greatest difference occurring between March and December for the morning tests and between March and September for the afternoon tests.

Field experiment

The results of the experiment done on the six subjects who spent a week away from the station shortly after mid-winter are presented in Fig. 6. The test done at 16.00 hr. immediately

TABLE I. MEAN BLOOD-SUGAR LEVELS AND CORRESPONDING MEAN INSULIN LEVELS (±SEM) DURING GLUCOSE TOLERANCE TESTS CARRIED OUT IN MARCH, JUNE, SEPTEMBER AND DECEMBER

	Blood sugar (mg./100 ml.)	Insulin (μU/ml.)		Blood sugar (mg./100 ml.)	Insulin (μU/ml.)
March			*June*		
08.00 hr.			08.00 hr.		
Fast	56±3	15±5	Fast	57±3	15±5
0·5 hr.	94±7	60±32	0·5 hr.	95±7	48±33
1·0 hr.	73±6	55±25	1·0 hr.	96±8	54±27
1·5 hr.	57±5	29±13	1·5 hr.	66±9	33±12
2·0 hr.	45±4	16±5	2·0 hr.	54±8	20±8
2·5 hr.	54±2	15±4	2·5 hr.	53±5	15±5
16.00 hr.			16.00 hr.		
Fast	52±3	15±6	Fast	56±2	12±3
0·5 hr.	85±5	45±34	0·5 hr.	89±5	30±15
1·0 hr.	95±8	50±26	1·0 hr.	98±8	36±14
1·5 hr.	77±7	37±20	1·5 hr.	84±9	33±16
2·0 hr.	67±5	28±15	2·0 hr.	66±7	22±8
2·5 hr.	52±2	15±4	2·5 hr.	56±4	13±4
September			*December*		
08.00 hr.			08.00 hr.		
Fast	56±2	10±5	Fast	47±2	14±6
0·5 hr.	92±6	30±14	0·5 hr.	78±5	31±16
1·0 hr.	91±8	36±15	1·0 hr.	59±3	27±15
1·5 hr.	66±5	24±10	1·5 hr.	46±4	20±7
2·0 hr.	55±3	16±7	2·0 hr.	42±3	13±5
2·5 hr.	52±3	10±4	2·5 hr.	41±3	12±4
16.00 hr.			16.00 hr.		
Fast	51±3	12±5	Fast	48±3	12±5
0·5 hr.	88±6	27±14	0·5 hr.	73±6	27±9
1·0 hr.	96±6	30±10	1·0 hr.	77±8	30±12
1·5 hr.	77±8	26±10	1·5 hr.	64±6	23±6
2·0 hr.	62±7	20±7	2·0 hr.	50±4	17±6
2·5 hr.	52±3	15±5	2·5 hr.	48±3	13±4

after rising showed a glucose tolerance pattern normally seen in morning tests. The GTT done at 08.00 hr. after the subjects had been up for 12 hr. showed a distinctly abnormal pattern when compared with morning or afternoon tests done at other times of the year, i.e. there was quite a marked decrease in the body's ability to deal with glucose, the glucose tolerance curve peaking at 1·5 hr. and remaining well above the fasting level at 2·5 hr.

DISCUSSION

The results presented in this paper show three features. First, there was a seasonal variation in the size of the difference between morning and afternoon GTTs, morning tolerance becoming progressively more impaired through June to September compared with March and December, and the morning curve coming to look more like the afternoon one.

The second feature was lower fasting glucose levels and a lower curve, denoting improved tolerance in December (summer) compared with the other times of year. The third feature was a seasonal variation in the glucose/insulin relationship as denoted by the different glucose/insulin regression lines.

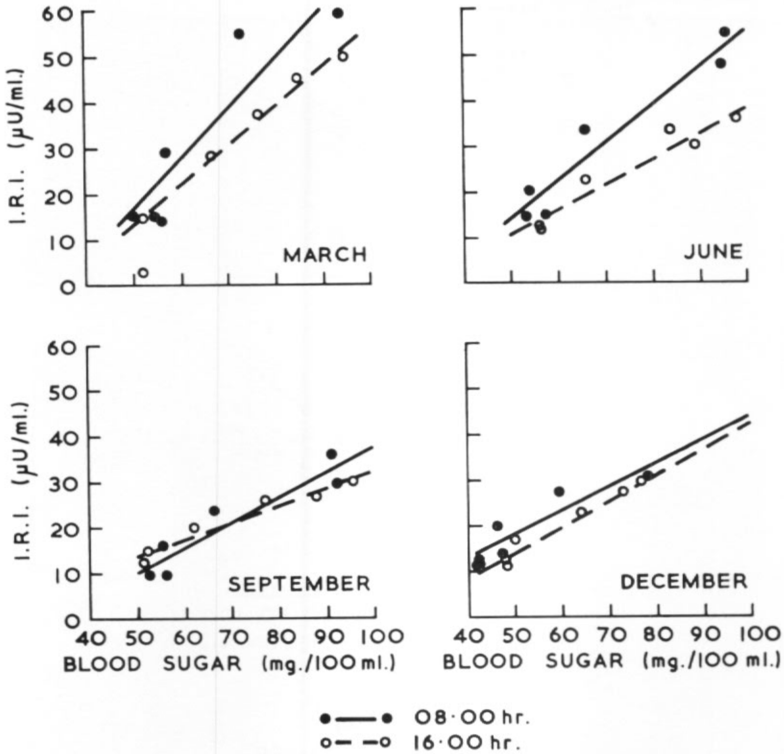

Fig. 4. Calculated regression lines for insulin (I.R.I.) and glucose during glucose tolerance tests done at 08.00 and 16.00 hr. at different times of the year.

Possible explanations of these features can be looked for in the various factors known to affect glucose tolerance in the individual (food intake, weight changes, activity) or in factors peculiar to the environment (periods of continuous light and continuous dark, and the large alterations in outside temperatures). All of the subjects were fit young men so questions of illness or drugs do not arise.

The diet was the same throughout the year and contained more than the 150 g. of carbohydrate recommended to precede a glucose tolerance test (Klimt and others, 1969). The period of fasting was the same in all cases. Energy expenditure measurements reported elsewhere (Campbell and others, 1975) showed, rather surprisingly, no significant difference in energy expenditure between seasons, although this finding was a little unusual in that previous energy expenditure measurements in the Antarctic have shown higher expenditure levels in summer compared with winter (Norman, 1965; Ohkubo, 1972).

The life style at Halley Bay was very much a function of the time of year. From early May to September people were confined to the station area and, apart from going out to perform only the necessary jobs and observations, they spent most of their time indoors. Pressures of work and routine were not as great as in a more civilized setting in that people had a job to do but generally only a rough time schedule in which it had to be done. Meals were served at regular times and scientific observations and radio schedules followed a fixed routine but there were no other real pointers to the time of day. Many adopted their own rather erratic routine which often varied from week to week, working late at night or early in the morning and taking naps at varying times of day. Lewis and Masterton (1957) noted the irregular

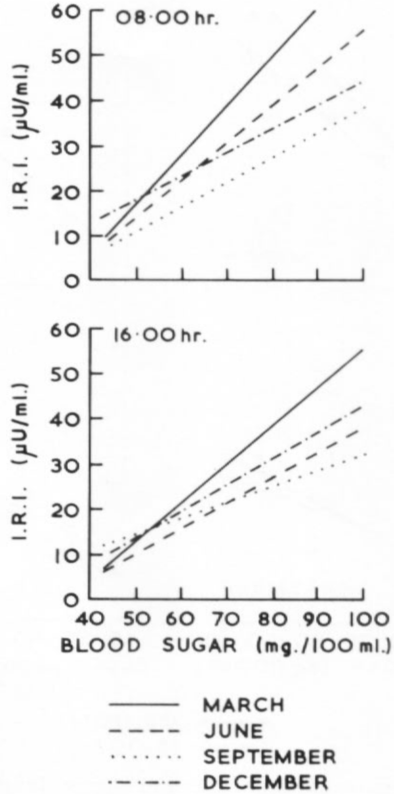

Fig. 5. Seasonal variations in calculated glucose/insulin regression lines

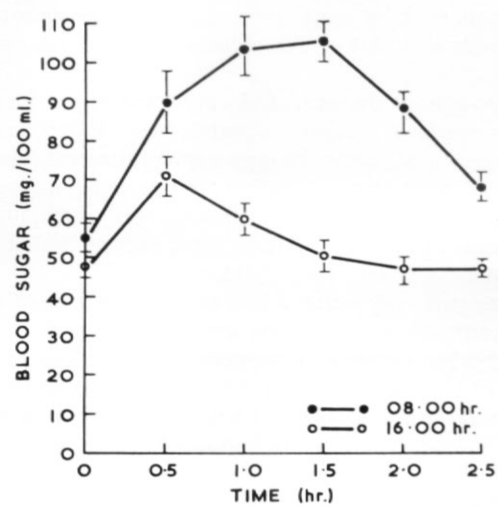

Fig. 6. Glucose tolerance tests done during the field experiment—mean blood sugar (±SEM).

sleeping patterns of men on the British North Greenland Expedition during winter and the difficulties many found in getting to sleep at the conventional times. Such was the experience at Halley Bay and has been ever since the station was built. During the summer when people spent much time out of doors working, visiting the coast 5 km. away, skiing or exercising dogs, the problem of adopting a regular sleeping pattern virtually disappeared.

This sleep/activity pattern over the year is reflected in the way the diurnal variation in glucose tolerance seen in lower latitudes and more civilized settings diminished through the winter months from March through June to September then became larger again in December. Whether this was cause and effect would be difficult to say but it would seem reasonable to suppose that it was.

During summer, subjects showed lower fasting glucose levels and improved tolerance compared with the rest of the year, i.e. the curves were lower both morning and afternoon. The effect of 24 hr. sunlight in the summer and the more open, more regular way of life could have some bearing on this observation. Light has been shown to affect blood-sugar levels in animal studies with increased sensitivity to insulin and lower blood-sugar values occurring during the summer months (Culhane, 1928; Young, 1965).

It would be difficult to find a precise explanation for the variability in the glucose/insulin relationship seen over the year and the difference between the morning and afternoon relationship seen in March compared with those seen in September. Similar variability in the glucose/insulin relationship has been noted previously. It has been seen within individuals given different oral glucose loads (Castro and others, 1970; Christensen and others, 1972), with obese individuals subject to physical training (Björntörp and others, 1970) and between intravenous and oral administration of glucose (McIntyre and others, 1964). From the results of the present study it would appear we can add environmental factors to this list.

Field experiment

Six individuals spent a week away from the station at mid-winter and, apart from the observer, none had any idea of the time of day. Their own "day" lasted 25–26 hr. At the end of a week a glucose tolerance test done at 16.00 hr., for which they had to be woken, showed a pattern similar to that normally seen at 08.00 hr. and in fact showed a better degree of tolerance than the 08.00 hr. test done on the station population at mid-winter. However, the two groups were of different sizes and composed of different individuals so a direct comparison is not really justified. In contrast to this, the test done at 08.00 hr. after the subjects had been up for 12 hr. was abnormal, demonstrating impaired tolerance, i.e. the curve was high. This suggests that tolerance is improved following a period of sleep, perhaps giving the insulin-producing cells in the pancreas a rest and a chance to recover but, despite the adoption of a more "natural day", the body does not seem to be able to cope as well with a glucose load late in that "day". This could be due to a relative deficit in insulin production or a variation in insulin sensitivity such as was seen over the course of the year. One wonders what sort of "afternoon" tolerance curve would have occurred if they had been allowed to continue with their 25–26 hr. day for a longer period. Would tolerance have improved, i.e. would the curve have come down, or would it have remained impaired?

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