COLD ACCLIMATIZATION IN ESKIMO

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On exposure to cold the body has a complicated physiological problem to solve. There is a limit to the heat it can produce to provide for an increased heat loss and during exposure of much severity a heat deficit is incurred. While peripheral tissues are cooling, the central body temperature must be kept within a very narrow range if the function of vital organs is to be maintained. If the accomplishment of this results in the failure to maintain a certain delivery of heat to the limbs, the usefulness of hands and feet is impaired. On the other hand if circulation to the extremities and to the surface of the trunk is greater than that required for necessary function, the heat loss is needlessly large and central body temperature is prejudiced. There is obviously room for subtle adjustment if vital needs are to be met and working capacity reasonably maintained in an economic fashion. It is the sum of the adjustments following repeated or prolonged exposure to cold which constitutes acclimatization to cold.

There has been doubt that acclimatization to cold exists in man. Many early experiments in the laboratory supported the view that it does not occur while observations in the field suggested that it does. The literature as a result is confusing. This is not surprising for the search for acclimatization had to begin before the nature of it was known. Often evidence was looked for in subjects thought to be acclimatized who actually were not. Another difficulty has been the selection of proper tests. The basis so far of all tests of acclimatization is a defined cold exposure and the observation of one or more physiological parameters. If the exposure is too severe, the test may be so indelicate that a real difference between subjects may not be apparent. Also, there has often been failure to recognize that there is in some respects a phasic response to continued exposure to cold. For instance, the blood volume is first reduced and then increased. It is, therefore, impossible to speak simply of the effects of cold. It is necessary to speak of the effects of one set of environmental conditions, temperature, air movement, humidity, and radiation, on subjects whose clothing is described and whose previous cold exposure is defined.

At a time when no physiological definition of acclimatization was available and it was not known how much exposure was required to achieve acclimatization, an attempt was made to get around the difficulty of finding fully

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acclimatized subjects by using Eskimo in the Canadian Eastern Arctic (Southampton Island) who were still carrying on their traditional hunting and trapping. Because of their performance in the cold it seemed safe to assume that these men were acclimatized though in the beginning uncertainty had to be admitted. It was also recognized that racial difference, experience in the technique of arctic living, dietary differences, and efficient clothing were factors which might have to be considered when data were interpreted. As it has turned out, the data on the Eskimo and data on Caucasians who have been subjected to cold over a really long period have together justified the choice of Eskimo as experimental subjects, and at present they are the group who have been studied most intensively.

Cardiovascular system

Vascular dynamics between acute cold exposures

Studies on Eskimo reclining comfortably in a room at 20°C and dressed in the same clothes as a control group of unacclimatized white men have shown differences in the pattern of the peripheral circulation and in cardiac action. They have a slower pulse rate than the control group and they also have a lower blood pressure (Brown, 1955). The latter has been remarked on by Høygaard (1941). The volume of blood flowing through their hands and forearms has been measured plethysmographically and it is about 75 per cent greater than that of the unacclimatized group (Brown and Page, 1952; Brown *et al.*, 1953). Skin temperatures recorded by thermocouples from twelve points on the trunk, arm, and leg show that the trunk, the shoulder, and the calf of the leg are kept at a higher temperature. The thigh and the great toe show no differences and the hand and forearm are significantly lower. Muscle temperatures have been measured with needle thermocouples and the muscles of the forearm, the thigh, and the calf are distinctly cooler in the Eskimo (Brown *et al.*, 1955). If the forearm and hand are covered with cotton wool, the hand skin temperature and the forearm muscle temperature are the same in the acclimatized and the unacclimatized and the forearm skin temperature becomes a little higher in the Eskimo. If more insulation is provided, as with a plethysmograph, both the hand and the forearm become warmer than in the controls and the forearm muscle temperature also rises. There is no difference in rectal temperature under these conditions. In summary, the Eskimo while maintaining the same rectal temperature as unacclimatized white men in the conditions specified have warmer skin over the trunk and the proximal parts of the limbs, cooler hands and forearms, and lower muscle temperatures in the limbs. The hands and forearms, however, are warmer in the Eskimo when a moderate covering is provided.

Few data have been obtained on acclimatized or partially acclimatized white men in the intervals between test exposures. Carlson *et al.* (1951) indicate in one of their diagrams that they found the hand temperature was higher in the acclimatized. More extensive data are provided by Balke *et al.* (1944) who recorded skin temperatures of men who lived for four weeks in

February in an unheated tent on a mountainside in the Tyrol. The air temperature seldom fell below -10°C and the men were dressed in army uniform and parka. Skin temperatures were recorded before bedtime and in the morning before getting up. Tabulation of the data presented in published graphs shows that there was a fall in the temperature of the abdomen, back, knee, and toe. If the records of the last five days are compared with those of the first five, the fall in temperature can be shown to be about the same at all four points. This work is not completely comparable with the work on the Eskimo. The basal metabolic rate of the subjects did not increase during the four weeks so that they cannot be considered acclimatized to the same degree as the Eskimo (*see* below). Also, the observations were in a sense made during the cold exposure. The men were comfortable in their tent in their heavy clothing but their faces were of course exposed. (The effect of cooling the face on peripheral vasodilatation is not known but Macht and Bader (1948) showed that at low ambient temperatures warming the face is more effective in increasing blood flow than is warming of other areas).

Vascular response to acute exposure

The vascular response of the Eskimo to acute cold exposure has also been shown to be different from that of unacclimatized white men. When the test exposure is the immersion of the right hand and arm in a 5°C water bath, the pulse rate remains slower in the Eskimo but the blood pressure reaches a higher level and it is maintained there during the 1-hour test (Brown, 1955). This could be due to greater cardiac output or to increased peripheral vasoconstriction in the Eskimo. Cardiac output has not been measured but there is good evidence of greater peripheral vasoconstriction. The reduction in blood flow through the hand and forearm is greater in the Eskimo though at all times during the test they maintained a greater blood flow than the controls. Despite the greater blood flow through the forearm, the forearm muscle temperature falls faster and farther in the Eskimo (Brown and Page, 1952; Brown *et al.*, 1953). This greater loss of heat from the forearm is to be explained by the greater flow of blood through the hand and hence the return through the deep veins of the forearm of a greater volume of cooled blood.

It has been seen that in the resting state the Eskimo have higher skin temperatures over the trunk and the proximal parts of the limbs and cooler hands and forearms than the controls. During the test exposure roughly the same profile of skin temperatures is maintained and the muscle temperatures remain lower than in the unacclimatized but there are significant differences of degree in the changes which occur. The average trunk temperature rises in both groups but more in the Eskimo. Skin temperature on the thigh and all muscle temperatures in the limbs fall farther in the unacclimatized. Rectal temperature is better maintained by the Eskimo during the test and the original level is regained within 30 minutes of its termination whereas the rectal temperature of the unacclimatized continues to fall significantly during the recovery period. Continued significant drops in temperature during the recovery period are seen in the unacclimatized on the forearm, hand, and in the muscles of the calf and forearm. In the Eskimo temperatures are maintained or even raised during the recovery period except over the forearm and hand (Brown *et al.*, 1955). It seems, therefore, that in meeting the stress of a moderately severe cold exposure the acclimatized Eskimo has an enhanced ability to maintain both central body temperatures and blood flow to the limbs.

Similarly increased resistance to cold has been repeatedly observed in white men when their previous cold experience has been sufficiently prolonged or intense. Horvath *et al.* (1947) exposed soldiers dressed in arctic suits to -29°C for eight days and found that the thigh temperature was better maintained in the later days of the experiment. Ames *et al.* (1948) placed men dressed in arctic clothing in a room at -40°C for sixteen 2-hour periods in the course of three weeks and found that shivering began later and that toe temperatures were better maintained in the later exposures. Glaser (1949) had men dressed in woollen underwear, shirt, trousers, and jacket spend two 72-hour periods in a room at -1 to -4°C with an intermediate interval of 72 hours in a hot room and he found that the second cold exposure was subjectively better tolerated than the first and that on the last day of the cold exposure the skin and rectal temperatures rose slightly. It is interesting that objective evidence of adjustment was found after such a short exposure. Carlson *et al.* (1951) reported increased blood flow in the fingers in men who had been in the Arctic for some months and were considered acclimatized. In later experiments he found that after daily exposure to the arctic winter for 16 to 18 hours for fourteen days there was a slower initial drop in hand temperature with maintenance at a higher temperature throughout the test exposure. He also found that there were increased differences between the temperatures of the rectum and the arm muscle, between rectum and leg muscle, and between the skin and muscle of the arm. At the end of the experiment removal of the jacket caused a smaller drop in hand temperature than it did at the beginning (Carlson *et al.*, 1953). As can be seen, practically all these studies have been done on subjects whose period of acclimatization has been quite short. What is still required is a study on white men who have been exposed to the cold for very much longer periods.

Carlson *et al.* (1951, 1952, 1953) formulated an hypothesis concerning acclimatization to cold which has excited the interest of all workers in the field. "This hypothesis states that on exposure a readjustment in circulation occurs which leads to warmer extremities and cooler body surface, and which tends to increase the effective body weight acting as shell" (1952, p. 22). According to this concept the shell is that part of the body which gives up its heat on exposure of that part or of some distant part of the body to cold. It has been Carlson's view that the contribution made by the shell is important and that it is greater in the acclimatized. There are several arguments which suggest that this may not be the case. Since the central body temperature, or core temperature, does not rise on exposure to cold except for very short periods, and since the temperature of the extremities falls, the contribution made by the shell must be part of the heat deficit incurred during a moderate or severe cold exposure. Horvath *et al.* (1947) found in men exposed for one hour in arctic clothing to very low temperatures that the heat deficit was incurred during the first ten minutes. After this period the stress must be met by heat from other sources than the shell. As has been seen, the trunk skin temperatures in the Eskimo do not indicate a cooler body surface as postulated by Carlson. Increased heat loss from the forearm muscles was noted in the arm placed in the cold water bath but in the other arm the drop in muscle temperature was significantly less in the Eskimo and a similar situation existed in the thigh and the calf. These regions do not, therefore, under the conditions of the experiment behave as part of the shell, which is at variance with Carlson's findings under admittedly different experimental conditions. Another possible point of difference is found in the extremities. In the hand directly exposed to the cold in the Eskimo experiments, the blood flow was always higher than it was in the control group. This was also the case when the legs were cooled, but when the hand was left uncovered at room temperature it was cooler in the Eskimo than it was in the control group. Finally, Carlson *et al.* (1951, 1953) postulated that metabolism supplies less of the total heat lost during acute exposure of the acclimatized person. The evidence available on oxygen consumption in the Eskimo is against this (*see* below) and Carlson's own work with animals has led him to reconsider his original suggestion which was based on studies on man (Carlson, 1955).

Metabolism

Basal metabolic rate

During cold exposure it is well known that heat production is increased but the full mechanism of this is still obscure. Increased activity of the thyroid has been suspected to be one of the contributing factors but the view that it occurs in man has often been questioned. In the Eskimo used in the present studies, the basal metabolic rate (B.M.R.) has been found elevated during the summer months (Brown *et al.*, 1954a). Unfortunately winter-time observations have not been made. Considerable care was taken to get readings under basal conditions and the subjects were as a result studied between 4.30 and 9.30 a.m. while still in their own beds. Usually the subjects were quieter and more at ease than are patients in routine hospital work. Determinations were made at fortnightly intervals between 11 July and 29 August 1949 and the average B.M.R. was 31.5 per cent, 27.6 per cent, 26.7 per cent, and 23.8 per cent above normal (Boothy and Sandford) on the four occasions. The fall during the summer is statistically significant.

The literature contains greatly varying reports of the B.M.R. in different groups of Eskimo. Levine (1937, 1939, 1949) in Alaska, Heinbecker (1931) at Pangnirtung, and Rodahl (1952) in Alaska reported that they found a normal average B.M.R. Rabinowitch and Smith (1936) working from a ship delivering supplies in the Canadian Eastern Arctic, Crile and Quiring (1939) at Chesterfield Inlet, Høygaard (1941) in east Greenland, Bollerud *et al.*, (1950) in Alaska, Heinbecker (1928) at Cape Dorset, and Rodahl (1952) in some of his subjects in Alaska found an abnormally high B.M.R. Examination of the reports shows that the B.M.R. is elevated in those Eskimo who are still adhering in an important way to their own culture but there have been many suggestions that the apparent elevation is false. Anaemia or unidentified disease (Levine, 1951), polycythaemia (Rabinowitch and Smith, 1936), racial characteristics (Gottschalk and Riggs, 1952), and a high protein diet (Heinbecker, 1931; Rodahl, 1952; Carlson *et al.*, 1953) have been suggested as causes of error. With care and proper clinical study of the subjects selected for testing, anaemia and other disease can be excluded. It is doubtful if racial origin is a factor, for an elevated B.M.R. is found in those of known mixed blood as well as in apparently full-blooded Eskimo. Neither is it likely that a high protein intake is responsible. McClellan *et al.* (1931) fed two men for twelve months a diet composed exclusively of meat and fat and reported only a slight and transient elevation of B.M.R. It is probable that an Eskimo group taking a high protein diet is a group still largely living the traditional native life, and that a group using a low protein diet is using important amounts of white man's food and very probably imitating him in other ways so that their cold exposure is reduced. This interpretation of the discrepancies in the estimates of B.M.R. in the Eskimo can also be applied to the work of Gottschalk and Riggs (1952) who found that the average serum protein-bound iodine was higher in the subjects studied at Southampton Island than it was at Chesterfield Inlet. The results of the assessment of thyroid activity, both by measurement of oxygen consumption and by determination of serum protein-bound iodine, indicate that any attempt to generalize about the Eskimo is mistaken and that the characteristics and conditions of life of the group studied must to some extent be defined if experimental results of any type are to be interpreted correctly.

There is similar variability in the reports on the B.M.R. of white men exposed to the cold. Balke *et al.* (1944) found no change in B.M.R. in their subjects and Ames and Goldthwait (1948) found no significant change in ten technicians during a three-month winter stay at Churchill, though their eleventh subject, a truck driver who spent considerable time out-of-doors, showed an increase of 30 per cent. Newburgh and Spealman (1943), on the other hand, reported that the B.M.R. in lightly clad men living in a room at 15°C increased after about ten days, and Horvath *et al.* (1947) found an increase in resting oxygen consumption after eight days in men dressed in arctic clothing and living at -29°C.

It seems reasonable to conclude that the apparently contradictory results of different workers are to be explained by the various durations and severities of the cold exposure involved and that when the exposure is long enough and severe enough an elevation of B.M.R. occurs. This is in line with extensive laboratory experiments with the rat (Ring, 1942) and the rabbit (Lee, 1942).

Metabolism during acute exposure

Oxygen consumption has been measured in a small group of Eskimo during the same test exposure as used in the other studies. The difference between the change in their oxygen consumption and that of the control group during exposure is not statistically significant, but there was a continued rise in oxygen consumption of the control group during the recovery period which suggests that they accumulated a greater heat deficit during the hour of exposure (Brown *et al.*, 1955). If this is so, the Eskimo met the heat loss to a greater extent by increased muscle activity or by increased visceral metabolic activity. If they are like acclimatized rats there is a greater increase in visceral metabolic activity than in muscle activity (Sellers *et al.*, 1954).

These data on oxygen consumption are not in agreement with the similarly scanty data available on white men. When Balke *et al.* (1944) brought their men down from the mountain and placed them in a 20°C bath for twenty minutes, they found the oxygen consumption during this exposure to be the same as it was before the four-week bivouac. Carlson *et al.* (1951) concluded that during a 1-hour exposure in an experimental suit to temperatures -8° to -32°C the metabolic rate increased less in the acclimatized than in the unacclimatized. It has already been pointed out that he is reconsidering the significance of this part of the results of those experiments.

If there is confirmation of the lesser oxygen consumption by the Eskimo during the combined exposure and recovery period, more evidence will be provided of the greater lability of the means of heat production or control which they appear to possess. Other evidence of this capacity was provided in the experiments in which blood flow and tissue temperatures were studied in the arms while the legs were heated or cooled and it is interesting that it was also observed in the warming experiments (Page and Brown, 1953). This seems in contradiction to the Eskimo's subjective reactions but these are the result of many factors.

Blood volume

Since the reports of Bazett and his colleagues (Sunderman *et al.*, 1939; Bazett *et al.*, 1940) that in white men in Philadelphia there was an increase in blood volume in the summer and a decrease during the winter, it has been the commonly held view that chronic exposure to cold causes a decrease in blood volume. There was support in the work of Spealman *et al.* (1947). It was as a result something of a surprise in 1950 to find in the Eskimo on Southampton Island a markedly elevated plasma volume (Brown *et al.*, 1954b). The average plasma volume about the middle of July was over 40 per cent above the accepted average normal and well outside the accepted normal range. During the summer the plasma volume fell but not to normal levels. The total red cell volume was also increased, though to lesser extent than the plasma volume and the fall during the summer was not as great. The elevation of plasma and total red cell volume has been recently confirmed but the fall during the summer was not studied again (Brown *et al.*, 1955).

It is probably the case that this is another of the apparent contradictions which are to be explained by difference in the previous cold exposure of the subjects. There is support for the view in this particular instance in the literature on white men. Conley and Nickerson (1945) reported that the reduction in plasma volume which occurred at the beginning of cold exposure was temporary and that the plasma volume had practically returned to normal after a few days. The reduction of plasma volume and the diuresis which occur on acute exposure are well known. It may well be that a slight exposure repeated over many months has only this type of effect and that a much more severe and continued exposure is required before the plasma volume not only returns to normal as Conley and Nickerson observed, but goes on to be increased. This, actually, is my view. It is consistent with the pattern of blood flow and skin and tissue temperatures which have been found in the Eskimo. It is also consistent with the elevations of B.M.R. and serum protein-bound iodine which have been found, for there is a roughly linear correlation between B.M.R. and plasma volume in the untreated hyperthyroid state (Gibson and Harris, 1939). The increase in plasma volume found in the Eskimo is of the same order as that reported in a series of cases of hyperthyroidism in which the average B.M.R. was +41 per cent (Goldbloom and Libin, 1935).

The elevation of blood volume found in the resting and fasting state led to investigation of the changes during the test exposure of placing the right hand and forearm in a 5°C water bath for one hour. Twenty minutes after the immersion the average Eskimo plasma volume was found to be decreased by 9 per cent, and in absolute terms this change was 30 per cent greater than that seen in the controls. Haematocrit determinations suggested that there was a further fall in the Eskimo and that there was a more rapid return to normal during the recovery period. An important point was that the urine output was the same in the two groups. The demonstration of a diminished plasma volume on acute cold exposure is not new but a difference between acclimatized and unacclimatized is, and the absence of diuresis of different size may mean that the initial phase of contraction of plasma volume is not to be explained simply by increased water excretion by the kidneys. The greater contraction of plasma volume in the acclimatized is consistent with the greater peripheral vasoconstriction and the pattern of changes in skin and tissue temperature seen in this group (Brown *et al.*, 1954b).

Ascorbic acid

Many interesting points have been noted in the blood and urine chemistry of the Eskimo. They include a low creatinine excretion, low urinary sulphate/nitrogen ratios, surprisingly low plasma lipids, high serum electrolyte/urinary electrolyte ratio, and a low plasma ascorbic acid/urinary ascorbic acid ratio (Brown, 1955). All these may be the result of dietary factors but the ascorbic acid findings deserve mention because of some experiments with white men. LeBlanc and Marier (1950, personal communication) found that in troops on a winter-time arctic exercise the urinary excretion of ascorbic acid was greater than it had been in the preliminary control period. LeBlanc *et al.* (1954) have also reported that the supplementing of survival rations (550 calories per day) with ascorbic acid 525 mg. per day was followed by an increase in average skin temperature and a decrease in the discomfort due to cold. In the Eskimo the average concentration of ascorbic acid in whole blood, plasma, and leucocytes has been found to be low, as might be expected, but the amount excreted in the urine was very much greater than in unacclimatized white subjects. In a loading experiment this was the case in both groups at two levels of plasma ascorbic acid. It may very well be, however, that this is due to a high intake of other nutrients and that it is not an effect of cold (Brown, 1955).

The concept of acclimatization which has arisen out of the work on Eskimo has as some of its features increased lability of the means of heat production or control, hyperactivity of the thyroid, increase in circulating blood volume, warmer skin over the trunk and proximal parts of the limbs, increased blood flow to the extremities, and better maintenance of skin and tissue temperatures during acute exposure. Before the validity of this concept is fully established, similar physiological changes must be demonstrated in white men and to accomplish this it will be necessary to plan more strenuous and prolonged experiments than any so far carried out. In new experiments many factors still unknown can be studied. The speed with which various degrees of cold acclimatization are acquired or lost is just hinted at in present experimental data. The order in which various features appear in different circumstances is not known. It may be different when the process of acclimatization is short but severe rather than long and less strenuous. There may also be differences when the face and extremities are chiefly exposed rather than the trunk. The importance in man of possible changes in the insulation provided by adipose tissue is not known.

It is possible that the degree of acclimatization seen in the Eskimo is not really important for any purposes but theirs. For the rest of us, lavish equipment, attention to the technique of arctic living, and simply more men may compensate for physiological inefficiency. If the only goal of work on cold acclimatization is the increase of the functional capacity of white men in the Arctic, it may be a relatively unprofitable field of endeavour.

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