THE EFFECTS OF ENVIRONMENTAL HEAT,

WITH SPECIAL REFERENCE TO ANHIDROTIC HEAT EXHAUSTION.

by

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PART I.

PART II.

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CHAPTER 1.

INTRODUCTION.

"Not one new plane designed after Pearl Harbour flew in this war despite the terrible urgency of conflict. All of our fighting planes were conceived and designed before this war!" Thus Brigadier General Graw, writing about research in aviation medicine, illustrated his plea that research must be done before war, not during the turmoil of conflict (Graw, 1947). This should, of course apply to all branches of medicine. Battle casualties during the war of 1914-1918 gave surgical research a tremendous impetus, and the recent war was entered on with further knowledge gained as a result of continued peacetime research. Some problems of tropical medicine, such as inoculation against typhoid fever and the control of malaria, were actively pursued between the wars, but the same cannot be said about research into the effects of environmental heat. While it is true that it is usually only when military personnel are on active service that large numbers of cases of heat effects syndromes can be studied, and the circumstances under which they occur are rarely favourable for research, this applies to most medical problems under war conditions.

Between the wars very few clinical observations or investigations on the effects of heat appear to have been made, and even the knowledge gained /

gained as a result of the enormous casualties due to heat in Mesopotamia in 1917 (when over 50 per cent. of the total deaths in British military personnel at the base hospital were from effects of heat) was not applied when greater numbers of men were exposed to the same risk in the second world war.

In 1868 Maclean pointed out the necessity for detailed observations on the effect of the wet and dry bulb temperatures on the incidence of the effects of heat, but it is only within the last few years that this has been studied. In 1927 Sundstroem pointed out that even the regions bordering on the semi-tropics offered opportunity for studying the effects of temperature and allied meteorological factors. Such regions were first used at Karachi in 1946. In 1868 Maclean, after discussing the tragic deaths from heat effects that were occurring in large numbers in India at that time, concluded that "as a rule, save under the pressure of real military necessity, European troops are not liable to be moved during the hot weather, and where such a cruel necessity exists, the terrible lessons taught during the Mutiny are not likely to be forgotten." In the summer of 1947, long after the cessation of hostilities, British troops are known to have died from the effects of heat while travelling in trains across the Sind desert. Emigrants from this country to Australia have died unnecessarily from heat effects in the Red Sea even more recently.

During a tour of India in 1942, Marriott stated that "there was not adequate shade provision for men, nor was there general realization of /

of the importance of extra salt intake. During the hot season there were 1959 admissions to hospital for heat effects and 136 deaths" (Marriott, 1947). Many recent observers have honestly admitted ignorance of important physiological principles and their clinical applications until the study of numerous cases of heat effects had enlightened them, by which time lives had been lost unnecessarily (Maclean, 1943, Shepherd, 1945, Stenning, 1945, etc.) Ignorance of the existence of certain syndromes has led to their being missed (Wolkin et al. 1944). Disinclination to accept important established observations has hindered progress - as recently as 1934 at least one large steel company in America advised against the use of salt in the treatment of heat cramps (Talbott, 1935), and Fay and Susman (1945) scoffed at recently published accounts of anhidrotic heat exhaustion, calling it a "doctor-made" syndrome. This syndrome has already been misconstrued by Taylor (1946); Waterlow (1947) has pointed out a fundamental mis-statement about it (as well as two other important errors) in an article on heat effects in the "Practitioner" (Kirk, 1946); and Murgatroyd (1950) has incorrectly stated that "water is chiefly required" for it in a recently published text book on medical emergencies.

Delay in understanding the mechanism of the production of the various heat effects syndromes has probably been aggravated by the belief that they were subject to some peculiar "tropical" influence, and by failure to interpret them in terms of known human physiology, pathology and climatology. For example, it was many years before the pioneer work of /

of Moss (1923) and others in deep mines in this country was applied to similar syndromes occurring in tropical climates. Failure to make important fundamental observations has also delayed progress - for example on the exact relationship of failure of sweating to the syndrome of heat stroke, which is still unknown.

The first publication of the extremely important observation that prickly heat is associated with a reduction of sweating does not appear to have been made until 1943 (Lipscomb, 1944) following the observations of a Medical Research Council research team (Ladell et al. 1944). The syndrome of anhidrotic heat exhaustion was not described until 1944 (Allen and O'Brien, 1944, Wolkin et al. 1944, Ladell et al. 1944), although it must have occurred ever since heat effects were observed.

The confusion that has long existed is reflected in the many conflicting classifications of heat effects syndromes that have been in use, and the freely interchangeable names applied to many different syndromes. No two standard text books agree on terminology, and even recent editions indicate continuing misunderstanding. This loose terminology also limits the value of published reports of cases of heat effects except where the names used for the various syndromes are qualified to indicate their precise nature.

Even a thorough comprehension of the effects of environmental heat may, of course, not always enable their occurrence to be prevented, especially under active service conditions. The "exigencies of the situation", which range from inefficiency of the quartermaster to the attentions /

attentions of the enemy, may be outwith the control of medical science, but the occurrence of certain syndromes is now inexcusable. Dehydration heat exhaustion and collapse may be interpreted, not as a failure of the body to adapt itself to heat, but as a successful achievement which has been sabotaged by failure to replace the salt lost in the sweat. This should rarely be allowed to occur, however difficult the circumstances. On the other hand, there is evidence to suggest that in certain environments it may be very difficult to strike a happy medium between too low or too high a salt intake, both of which may be deleterious.

Experimental work on the effects of environmental heat was done before the last war in America by several groups of physiologists, and their conclusions applied to the greater comfort of residents in that continent, but experimental work designed with application to war service conditions was started too late, both in Britain and America, to be of much benefit in the last war. And in any case, many of the theoretical conclusions based on experimental exposures to simulated hot environments have a limited application to working conditions in a hot climate, but even those that do (such as the mechanism of acclimatization) did not appear to be applied to any real advantage.

However, in spite of a large casualty rate, the recent war did dispel the idea that Europeans have difficulty in adapting themselves to tropical climates, other than psychologically, and proved that the Englishman can accompany the mad dog in the mid-day sun, and survive. The sight of the relative déshabillé of thousands of British troops who worked /

worked and fought in the Middle and Far East would have shocked the devotees of the topee and spine-pad of only a generation ago. Indeed, it has been shown that young and healthy acclimatized Europeans can work harder in the tropics than some of the local inhabitants (Ladell,1948). Often they are not given a fair chance, however, and many cases of heat effects occurred immediately after disembarkation from troopships before adequate acclimatization could take place (for example, 71 cases on one occasion in the Middle East reported by Croom, 1944). The Americans were not exempt from this failing, and Machle (1945) reported cases of heat effects among troops leaving air-conditioned trains and immediately setting up camp at a desert training centre. He stated that the lesson was learned, however, and applied two weeks later with a new division, and, although the climate was the same, there were very few casualties. The British did not appear to apply the lessons of Croom's experience when subsequent troopships arrived. Artificial acclimatization of troops prior to their being sent to the tropics has been frequently mooted, and it was stated that the Germans trained tank crews of the Afrika Corps in hot rooms before they left Europe, but no evidence is available that this really happened.

Experimental research is continuing in this country, in America, and in the East, but what appears to be urgently required is an appraisal of all the experimental and clinical evidence available, with a view to clarifying the different heat effects syndromes as they occur in the field, so that they can be prevented whenever possible, and adequately treated /

treated should they occur. That is the purpose of this clinical-physiological review, based on a study of the literature, personal clinical experience over four consecutive years in hot climates, and a detailed study of one particular syndrome. The frequency with which it is necessary to resort to hypothesis reveals the large gaps still present in the understanding of the effects of environmental heat, and the necessity for further work.

Part I consists principally of a general review of the clinical syndromes that occur as a result of exposure to environmental heat, preceded by an account of the relevant physiological and climatological factors. Part II consists of original observations and experimental work by the author. A detailed study of the literature on heat effects since the beginning of the nineteenth century has been made, principally in order to be able to assist in the interpretation of these tropical observations.

CHAPTER 2.

PHYSICAL ASPECTS OF HEAT REGULATION OF THE BODY.

Man is a warm-blooded (homoiothermic) animal and possesses an efficient mechanism for maintaining a more or less constant body temperature. The human body is capable of functioning over a considerable range of temperature, though brain cells cannot survive long when the blood temperature is 106 deg. F. or over. The optimum temperature of 98.4 deg. F. is maintained by a balance being struck between "heat gain" and "heat loss".

Heat production is principally the result of chemical reactions, and may be considerably increased by physical exertion and in fever. It cannot be reduced by more than about five to ten per cent. below its basal level. When the temperature of the environment is higher than that of the body, heat will be transferred to the latter by physical processes. The degree of effort required to dissipate the combined metabolic and exogenous heat in order to maintain thermal equilibrium is known as "heat stress" (heat strain, heat load). The magnitude of heat stress is the product of its intensity and duration.

Heat transfer between the body and the environment takes place by means of radiation (R), convection (C), and evaporation (E). Conduction plays almost no part, except in the transfer between the skin and deeper tissues /

tissues. In a state of strict equilibrium, heat production (M) is equal to heat loss (= R + C + E) but of course in a hot environment R and C may be negative quantities. Allowance must also be made for the fact that the body is capable of storing heat, and so the formula should be

$$M + S = R + C + E$$

where S is heat storage. Since the body may either gain or lose heat by R and C, the formula modified to meet all situations would be

$$M \pm S = E \pm R \pm C = 0$$

This necessitates the convention of "positive" or "negative" storage. Heat transfer is obviously modified by clothing.

The rate of exchange of heat depends on the difference in temperature between the body and its environment, being less as the two are approximated. As long as the environment is cooler than the body metabolic heat can be dissipated by radiation and convection, but if the environment is warmer heat will be transferred to the body. The loss of heat by evaporation from the lungs is relatively so small as to be unimportant. A small amount of heat is continuously being lost from the surface of the body as a result of evaporation of insensible perspiration, but when the air temperature is approximately 31 deg. C.(88 deg. F.) the nude body at rest requires the secretion and evaporation of sweat in order to maintain thermal equilibrium (29 deg. C.(84 deg.F.) lightly clothed)(Evans,1945). The greater the heat stress the more sweat for evaporation is required, but of course sweat which drops off the skin gives no contribution to heat loss. The rate of evaporation of water varies inversely with the relative /

relative humidity of the air, and can be greatly augmented by increasing air movement. Sweating also has the effect of allowing more heat to be lost to the air without increase of the surface temperature, since the relative humidity of the skin varies closely with its thermal conductivity (Mole, 1948). Sweat contains approximately 0.2 - 0.3 per cent. of salt.

At body temperatures the skin radiates for all practical purposes as a perfectly-black body. The principal factor influencing heat exchange through radiation is the temperature of surrounding objects relative to the skin. Humidity of the air interferes with the transfer of radiant energy. Radiation occurs from approximately 85 per cent. of the total surface of the body, and so posture may be quite an important factor in heat regulation when radiation temperatures are high.

The heat lost by convection varies with the temperature of the air, but does not vary much with its humidity. By "natural convection" is meant that due to movement of the air heated by a warm surface, and by "forced convection", any addition due to movement of the limbs or to air streams. Heat loss by convection is enhanced by air movement up to a velocity of about 70 m.p.h. If the air is hotter than the body, there will of course be considerable heat gain by the process.

The regulation of heat balance is probably controlled mainly by centres in the hypothalamus, and takes place through the autonomic nervous system. The principal mechanical factors concerned are the distribution of the blood, the blood volume, and the circulation rate, and, when these are inadequate for heat loss, sweating.

These /

These and other physical aspects of the heat balance of the human body are dealt with fully in standard text books of physiology. Recent reviews of particular interest have been made by Brunt (1947), Du Bois (1948), and Newton (1949).

The dry bulb temperature is an inadequate expression of heat stress imposed by the atmosphere, and a commonly used expression is the "effective temperature", which also takes into account the humidity of the air and air movement. The "corrected effective temperature" also considers the radiation temperature. This concept was first suggested by Yaglou and other members of the American Society of Heating and Ventilating Engineers in 1925, and is summarized by Bedford (1946), who also describes the apparatus necessary for its measurement.

CHAPTER 3.

PHYSIOLOGICAL ADAPTATION TO HEAT.

The body has a remarkable power of adapting itself to heat, thus allowing existence and even healthy activity in hot environments. Many factors are concerned in this process of adaptation.

CIRCULATION.

While a certain amount of heat can be transferred by conduction from the deeper tissues of the body to the surface, the main burden is borne by the circulatory system, and its adjustment for the task is essential if heat transfer is to be adequate to maintain thermal equilibrium. It acts by increasing the blood flow through many parts of the body; through the skin in order to allow of cooling and to supply the sweat glands with adequate fluid; through voluntary muscles in order to remove the heat produced there; through the lungs in order to provide adequate respiratory exchange and to assist in evaporative cooling; and through the alimentary tract in order to transfer water from there to the surface. The adjustment is made by increasing the minute volume of the heart, by alterations in the vasomotor mechanisms, and by an increase in the blood volume.

The enhanced action of the heart is similar to that produced in response to physical exertion, and the minute volume can be increased to about /

about three times its resting level. Cutaneous vaso-dilatation is controlled by reflex mechanisms, and the resultant raised skin temperature allows of increased heat loss from the skin by means of evaporation, radiation, and convection. Even after two to four hours of exposure to heat stress sufficient to produce general cutaneous vaso-dilatation there may be an increase in the total circulatory blood volume by about 10 per cent., but there may be even greater increases after more prolonged exposure to heat (Bazett et al.,1940, Conley and Nickerson, 1945, etc.)

Physical work puts an additional stress on the circulation, and even maintenance of the erect posture will increase the stress because of the gravitational pooling in the veins and capillary beds of the lower part of the body. On exposure to heat there must be a continual struggle between cutaneous vasodilatation in order to lose heat and vasoconstriction to avoid pooling. It is to be expected that a sudden call on the circulatory system to make this adjustment without experience will result in a breakdown of the system.

The range of increase in cardiac output under heat stress is probably up to about one and a half litres per minute, and it has been demonstrated that the increase shows no great variation between the resting and exercising state (Adolph et al.,1947). On the other hand, the cardiac rate increases proportionately to heat stress, depending partly on posture and degree of work. Resting rates above 140 per minute are rarely reported, and when 170 to 180 is reached there is great distress and collapse is imminent. Experimental clinical observations on syncope are /

are discussed in chapter 7.

It is obvious that dehydration with resulting reduction in the plasma volume will embarrass the circulation and lead to an earlier breakdown of the system. Pitts et al. (1944) and Adolph (1946) have found that water deficits of only 1 to 2 per cent. of body weight lead to increased circulatory strain, as shown by increases in heart rate and in rectal temperature, and greater deficits increase the strain further.

WATER AND SALT BALANCE.

Sweating.

The water output in a hot environment depends principally on the amount of sweating required to maintain thermal equilibrium of the body. A great number of investigations have been carried out on the control of sweating and its rate, and on the salt content of sweat, during exposure to heat. This has been reviewed in detail by Ladell (1945a) and Robinson (1949), and the principal conclusions are as follows.

There is a latent period before sweating begins after exposure to heat, which varies in individuals, and which is shortened by increasing the intensity of the heat and by acclimatization of the subject to heat. The rate of sweating depends mainly on skin temperature, and to a less extent on deep body temperature. It is modified by individual variation and by acclimatization. Extremely high rates (up to 3 or 4 litres per hour) can be achieved for short periods by well acclimatized subjects. Unacclimatized subjects may sweat unnecessarily freely, but the rate settles to a more economic level after more prolonged exposure.

It has been shown recently (Randall and McClure, 1949) that the excitation /

excitation of the sweating mechanism by mild muscular exercise is marked chiefly by an increase in the number of active sweat glands with little or no increase in output per gland. Upon more severe stimulation such as accompanies partial immersion in hot water, an increased number of functional glands may be supplemented by increased output per gland in a given period of time.

The sweating mechanism appears to be fatiguable when extremely high rates are called for (Ladell, 1945a, Gerking and Robinson, 1946), more so in humid than in dry heat (Robinson and Gerking, 1947). The decline is independent of falling skin or rectal temperatures, dehydration, salt deficiency, and lack of acclimatization, and is a factor limiting tolerance to prolonged exposures on account of accumulation of heat consequent on inadequate evaporation of sweat. While it has been suggested that the reduction of sweating may be a useful adaptation in case of water shortage, and so postpone dehydration, this reduction would appear to be of greater importance as a possible explanation of the complete breakdown of the heat regulation mechanism in heat stroke.

Neither moderate water deficiency nor excess drinking of water influence the sweat rate significantly. Different areas of the body have different sweat rates, and this varies in individuals. The maximum ability to sweat increases with acclimatization, and there are wide individual variations. There may be a greater development of sweat glands in residents in hot environments.

High rates of sweating may lead to hypochloraemia of an important degree, unless the salt loss is replaced. There is great individual variation /

variation in the chloride concentration of sweat, and in the sweat from different regions of the body. There is conflicting evidence on the effect on the sweat chloride of the rate of sweating and its duration, rectal temperature, salt and water intake, and plasma chloride concentration, although there is good evidence that it is directly related to skin temperature (Robinson et al.,1950a).

It is generally agreed that there is an initial decrease in the sweat chloride during acclimatization to heat which would appear to have a sound physiological basis with the object of conserving salt, but the mechanism by which it occurs is not fully understood. It may simply be due to the lower skin and rectal temperatures of acclimatized subjects, though evidence has been presented that it may be associated with stimulation of the adrenal cortex (Moreira et al.,1945, Ladell, 1945b, and Conn et al.,1947), though this was not confirmed by Robinson et al. (1950b).

The rising chloride concentration of the sweat during single exposures to heat reported by several authors has been interpreted as a "fatigue" of the sweat glands, but there is no confirmation of this. The change in sweat chlorides during a period of several months' residence in a hot humid climate are described in chapter 13. Preliminary observations of Weiner and Heyningen (1949) led them to believe that changes in the sweat glands with regard to lactic acid may occur in acclimatization.

Water intake.

Thirst is the principal factor regulating water intake, but it does not necessarily reflect the state of hydration of the subject. A critical /

critical review of the literature covering the mechanism of thirst has been made by Dill (1938). Observers have repeatedly noted that even experienced and fully acclimatized subjects (including miners) working in the heat never voluntarily drink as much water as they lose in the sweat, although the deficit may be restored during periods of rest. It has been found that men are more likely to keep themselves hydrated if the salt loss is replaced at short (e.g. hourly) intervals. The highest rates of sweating found in hot climates are much below the critical rate above which oral replacement of fluid lost in the sweat becomes impossible, at least in short experiments (Ladell, 1945a), but Caplan (1949) found that miners in the Kolar gold fields could not replace the loss of fluid, approaching ten pints during a shift, without vomiting. Most men can drink water equal to the sweat loss without the appearance of a diuresis or a lowering of the refractive index of the plasma (Rothstein and Adolph, quoted by Robinson, 1949). The effect of dehydration on the circulatory system in heat regulation has already been discussed.

Kidney function.

The kidney helps to maintain water and salt balance by reduction of excretion of these substances when the body sweats as a result of exposure to a hot environment. Chloride may disappear entirely from the urine, whose volume may be reduced to 400 or 500 c.c. per day, although the specific gravity rises on account of an increased concentration of total dissolved substances.

Body temperature.

The rectal temperature is usually accepted as representing the internal body temperature, but calculation of the mean body temperature must include measurement of the skin temperature. Both the rectal and skin temperatures rise, though at different rates, when the subject is exposed to increasing environmental temperature, and to a greater extent when work is done. All the adaptations discussed above are ultimately concerned in the control of these temperatures, but they do not necessarily maintain the rectal temperature at a normal level, even when the body is functioning adequately. Work may be done better when the body temperature is slightly raised, and there appears to be an alteration in the thermostat setting depending on the metabolic rate. Only when the rectal temperature is considerably raised, does evidence of exhaustion and the threat of heat stroke occur. Adequate adaptation of the circulation and the sweating mechanism allows the regulation of the body temperature, which improves on acclimatization. The upper limit of body temperature compatible with survival is probably about 43 deg. C. (rectal).

There is conflicting evidence as to whether or not the rectal temperature is permanently raised above the accepted normal level in hot environments. Recently, Burton et al.(1940) concluded that it is not, Renbourn (1946) that it is.

Respiration.

Pulmonary ventilation plays a relatively small part in the maintenance of human thermal equilibrium, though it is definitely increased when the /

the body temperature is raised. This hyperpnoea may result in alkalosis.

Metabolism.

The basal metabolism is increased for several days on exposure to a hot environment, but subsequently returns to normal, and after several months' residence in a hot climate it may fall below normal basal standards (Knipping, 1923, Munro, 1949, etc.) although Lee (1940) has suggested that the low results obtained are due to more complete relaxation of skeletal muscle during the tests. It has been suggested, as a result of experience with animals exposed to heat and cold, that if there is a true lowering of the basal metabolic rate it may be associated with alteration in thyroid activity.

CHAPTER 4.

TOLERANCE TO HEAT AND ACCLIMATIZATION.

Tolerance to heat.

There are several examples in the literature of the amazing capacity of the body to withstand great extremes of heat for short periods of time, but these are of little other than historic importance since they are very rarely necessary. Nowhere on earth does the daily maximum shade temperature average more than 120 deg. F. in the hottest month of the year, and the highest temperature ever recorded was 134 deg. F. in Death Valley, California. Conditions much worse than this, however, may occur in artificially hot environments, such as the stoke-holds of ships and deep mines. Experimental and field experience has shown that the wet bulb temperature is the most important limiting factor, especially in the absence of good air movement. Conditions tolerable at rest may be intolerable when work has to be undertaken.

The limit of human tolerance to heat in terms of temperature level and time can be calculated on the theoretical consideration of heat exchange between the body and its environment. This has a restricted practical application, although Brunt (1949) claimed good correlation between his calculations and experimental determinations, and Robinson et /

et al. (1945) reported that the theoretically computed "thermal acceptance ratio"[1] appeared to correlate fairly well with physiological responses to heat and muscular work.

Eichna, Ashe et al. (1945) summarized the many investigations carried out in naturally occurring hot climates, in the extreme heat of mines and factories, and in laboratory hot rooms, and themselves confirmed the early conclusions of Haldane (1905) that the wet bulb temperature is the limiting factor which in practice determines the ability of man to retain thermal balance in his surroundings. They demonstrated the upper levels at which work could be carried out by their subjects easily or with difficulty, and the level at which it was impossible, in saturated and unsaturated environments. Haldane (1905) and others have also shown that this limiting wet bulb temperature rises as air movement increases.

Robinson et al. (1945) showed experimentally the effects of environment on men in relation to their activity and clothing in six contour graphs in which their "indices of physiological effect"[2] were plotted in relation to dry and wet bulb temperatures and relative humidity. Ladell (1947) also summarized important experimental work in this connection, and gave nomograms showing the contour lines of limiting environments for men uniformly dressed, working at different rates, and under different environmental conditions.

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[1] Proposed in America by the Climatology and Environmental Protection Branch of the Office of the Q.M.General as an index of heat tolerance. It is the ratio of maximum heat stress that can be safely tolerated to the actual strain imposed by heat and activity - a tolerance safety factor - estimated from an arithmetical expression (Siple, 1949)

[2] Obtained by weighting equally the elevation of the subject's heart rate, rectal and skin temperatures, and rate of sweating from the base values of these functions determined in a cool environment on each subject in each activity.

These experimental studies are valuable in understanding the physiological responses to heat, but have a limited application in the field because of a number of other operative factors, and the environments in which men sometimes do work without casualties occurring appear to be beyond the limits determined experimentally, as well as beyond the theoretically calculated limits. Sometimes physiological data are incomplete, or neglect important factors. For example, the conception of the "wettedness of the skin" (Gagge, 1937) has been criticized by Mole (1948) on various counts, including the fact that its physiological interpretation seems improbable. More accurate conclusions on the upper environmental limits of thermal equilibrium can be reached by considering the relative humidity of the skin.

Attempts have also been made to define the limit of tolerance to heat by assessing the incidence of heat casualties in relation to climatic conditions (for example, the "heat death line" of Shickele (1947) based on 125 cases of heat fatalities among soldiers in training in U.S.A.), but these are also of limited value because of the large number of variables. In the paper quoted, for example, the influence of wind and radiation was ignored.

Any such estimates of the limit of tolerance must take into consideration the state of acclimatization of the subject (see below) and the particular circumstances in which the heat has to be tolerated, such as the type of work to be undertaken. In addition there is known to be considerable individual variation in the reaction to heat.

While /

While it is therefore difficult to express the limit of tolerance to heat in terms of environmental conditions unless many other factors are taken into consideration, it is known that individual tolerance to any particular circumstances can be considerably increased. This is known as "acclimatization to heat".

Acclimatization.

The ability of the human body to function properly in a hot environment depends primarily on its ability to adapt its heat dissipating mechanism. This has been shown to involve principally adjustments in the circulatory system and the sweating mechanism, designed to increase heat loss from the surface of the body. The limit of tolerance measured in terms of environmental conditions will therefore depend on the limit of adaptability of these two mechanisms. This is not fully revealed at the initial exposure to heat, and the optimum response can only be obtained by prolonged exposure at levels below the limit of tolerance, or by repeated interrupted exposures. By means of this process the body can eventually tolerate environments that would be lethal in the "unacclimatized" state. The acclimatized subject is able to live in a hot environment with a greater feeling of comfort, and to work in it with a minimal disturbance of pulse rate, blood pressure, and body temperature.

Many detailed studies of the mechanisms involved have been made during and following intermittent exposures to heat, but little accurate information is available about the effects of prolonged exposures. Almost all the experimental work has been carried out in temperate climates /

climates with groups of subjects exposed to hot environments for short periods daily, and in a few groups for continuous periods up to three weeks. However, these investigations have revealed several important principles:

(1) There is considerable individual variation in the rate of acclimatization and in the degree ultimately acquired.

(2) Physical exercise in the heat is necessary during acclimatization if the former is ultimately to be carried out successfully.

(3) Good acclimatization can be achieved even if the exposure to heat is intermittent.

(4) Acclimatization to humid heat involves a greater adaptation of the cardiovascular system; dry heat, of the sweating system.

(5) Acclimatization to dry heat does not give comparable acclimatization to moist heat, and vice versa.

Loss of acclimatization.

It has been shown that repeated intermittent exposures to heat increase the tolerance to such exposures, and it is probably fair to conclude that they would increase to some extent the tolerance to continuous exposure. Men who are called upon to work intermittently in the heat, such as in deep mines and steel works in temperate climates, or to wear protective clothing, do not appear to lose their acclimatization as a result of periods that they spend in a normal environment. But if these regular exposures are interrupted acclimatization is soon lost. Moss (1923) found that if miners, working in deep mines in very hot environments /

environments, were off on holiday for a few days, they were "good for nothing at the end of a shift" for the first few days after return. A similar rapid loss of acclimatization was noted by Caplan (1943) and Dreosti (1949) among workers in deep gold mines, and Collings et al.(1943) in an analysis of 437 cases of "heat disease" in a steel mill, showed that nearly half of the cases had not been working the day before. Experimentally, Machle (1945) found that men, after an exposure to an artificial hot environment might retain acclimatization for from two weeks to two months. Bazett et al. (1940) showed that changes in blood volume following exposure to heat were rapidly reversed after a few days of cooling, and Munro (1949) showed that a few days' residence in a cold hill climate was sufficient to raise the basal metabolism of a group of British subjects significantly above their tropical level.

Residence in a hot climate of the desert type is in some ways similar to the "intermittent" exposures described above, because of considerable lowering of the environmental temperature overnight. In the "humid" tropics there may be no such relief for many weeks on end, and it is of interest that in one of the few experiments involving prolonged exposure to heat, Eichna, Ashe et al. (1945) found that while there was the expected initial acclimatization, there was some demonstrable deterioration after ten days in humid heat.

Other /

Other aspects of acclimatization.

Studies on acclimatization in artificially produced hot environments have a limited application to actual life in hot climates, where it is essential that there should be also a psychological adaptation, not only to the measurable features of the climate, but to all the other immeasurable aspects of the environment associated with the climate. The word "accustomization" has been coined by Siple (1949) to express this phenomenon. It is not justifiable to compare in every respect the effect of a voluntary experimental period in a hot room (with the prospect of relief at the end of a few weeks at the longest) with the effects of an involuntary period in a hot climate (often without the prospect of relief for some considerable time). Even the relief of "two five-minute periods for lavatory privileges" described in the experiments of Machle (1945) might have had a profound effect on the psychological adaptation of his subjects, even if it had no effect on the physiological adaptation, and if any influence of the "psyche" over the "soma" is accredited, then this aspect may be of importance, even in results that can be measured physiologically.

Machle (1945) confirmed the well-known observation that adequate sleep is necessary for the successful performance of work on the following day. Sleep is notoriously difficult in the hot humid type of climate, which can, of course, be simulated experimentally, but effective temperatures overnight in the tropics are sometimes much higher than is usually believed, and the aggravating effect of a mosquito net cannot be assessed only /

only in terms of the reduction of air movement that it causes. Sound sleep is usual at a wet bulb temperature of 81 deg. F. but rare at 85 deg.F. (Adolph,1946).

In addition, the investigations of Weiner and Hutchinson (1945) on the effect of a hot humid environment on the performance of a motor co-ordination test are important. They found that performance of the test was impaired in this environment, and that elevation of the rectal temperature did not necessarily increase the impairment. They concluded that "acclimatization" of motor co-ordination analagous to that for work might take place. This might be distinct from physiological acclimatization to work in a hot room, as several subjects who were already acclimatized in this way showed impaired co-ordination performance.

The process of acclimatization also includes an alteration in the comfort sensation, which is presumably due to modification of central and peripheral factors. Yaglou (1926) showed that the"comfort zone" lies between different limits according to acclimatization of the individual. The author has been able to demonstrate the sensation of cold and the goose-flesh reflex in individuals long acclimatized to heat when they entered an air-conditioned room at the relatively low effective temperature of 70 deg.F.

Acclimatization may also involve alterations in the functioning of the endocrine system, especially the thyroid, adrenal (Ladell, 1945b, Conn et al.,1946) and pituitary glands, which in turn may have psychological implications. Even disinclination for physical activity, not allowed /

allowed for in experimental work, may be a feature of acclimatization to heat. The often criticized lethargy of natives of the tropics (sometimes considered an aggravating factor in the production of heat effects syndromes in Europeans!) at least spares their heat dissipating mechanism, and may help to account for the relatively low incidence of heat effects compared with that among Europeans. And finally, as Sundstroem (1927) pointed out, "the equality of the tropical climate itself may constitute a separate meteorological factor to be reckoned with in tropical adaptation."

These last mentioned processes are unlikely to be demonstrated in short term experiments in artificial environments, and further field studies are necessary for the complete understanding of acclimatization.

CHAPTER 5.

A CLASSIFICATION OF CLINICAL SYNDROMES RESULTING FROM HEAT STRAIN (HEAT EFFECTS SYNDROMES).

In view of the diffuse terminology used at present for the different clinical syndromes resulting from heat strain, commonly called "heat effects", it is necessary in order to discuss the subject to accept an arbitrary classification. The one to be used here is given in Table I, and an attempt will be made to justify it in the subsequent discussion.

Two syndromes, "heat cramps" and "heat stroke" are clinically fairly clear cut, although the exact mode of action of their characteristic aetiological features has not yet been determined, and they will be dismissed temporarily without further discussion.[1] Other syndromes are characterized by varying degrees of "exhaustion", sometimes to the extent of actual "collapse", and while it is apparent that sometimes the cause of the exhaustion and the collapse may be the same, differing only in degree, the clinical picture of the two may differ considerably. Accordingly two types of syndrome can justifiably be recognized, "heat exhaustion" and "heat collapse". The former term is in some ways rather misleading, since it embraces a large range of conditions from slight fatigue that may be of no importance, to a stage in which clinical evidence of collapse is not obvious, but which nevertheless may not be far removed from /

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[1] They are fully described in chapter 7.

TABLE I

A classification of heat effects syndromes.

Main aetiological factor	Clinical syndrome
Chloride deficiency	Heat cramps Dehydration (hypochloraemic) heat exhaustion Dehydration (hypochloraemic) heat collapse (Alimentary symptoms)
Circulatory deficiency (exercise precipitated)	Circulatory heat exhaustion Circulatory heat collapse
Vasomotor deficiency	Heat syncope
Sweating deficiency "chronic" "acute" (or ? failure of heat regulatory centre)	(Anhidrotic heat exhaustion (Anhidrotic heat collapse) May progress (Heat hyperpyrexia[1]) to heat ( ) stroke ((Heat stroke[1]
Psychological	Tropical neurasthenia

Other syndromes

Heat oedema.

Prickly heat

Sunburn

Water deficiency (uncomplicated) resulting from heat strain is very uncommon. Thirst, great weakness and oliguria are the prominent features (Marriott, 1946).

[1] "Secondary heat hyperpyrexia" and "secondary heat stroke" apply to these syndromes, respectively, when heat strain is added to by a pyrexial illness.

from peripheral circulatory failure and possible death.

Each of these two syndromes requires to be further qualified in such a way as to show what is the principal mechanism (usually failure of a mechanism) concerned, although in many cases mixed aetiologies are present, and it is not always possible to attribute the syndrome entirely to one of them. Failure of the circulation and failure of sweating are the two principal causes (and the latter may aggravate the former), and so the syndromes "circulatory" and "anhidrotic" heat exhaustion and collapse are recognized. "Heat syncope" is preferred for failure of the circulatory system under special conditions in view of the conventional use of the term "syncope".[1]

Chloride deficiency occurs as a result of heat strain if there is inadequate replacement of salt lost in the sweat, and while it usually manifests itself clinically through the effects on the circulatory system as a result of the dehydration, it is of such fundamental importance in aetiology (and in treatment) as to justify the separate classification of "dehydration heat exhaustion" and "dehydration heat collapse".[2] Chloride deficiency sometimes shows itself in other ways (apart from "heat cramps" which have already been mentioned), particularly as alimentary symptoms, but these do not appear to justify a separate title.

Water deficiency alone resulting from heat strain is extremely uncommon /

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[1] Chapter 7.

[2] This syndrome is fully described in chapter 7. "Oligaemic" or "hypochloraemic" is sometimes employed in place of "dehydration", although symptoms can apparently develop when the plasma chloride is within the accepted normal limits.

uncommon, and occurs only under special circumstances, such as among survivors of shipwreck. Thirst, great weakness, and oliguria are usually the most prominent symptoms (Marriott, 1947).

Failure of psychological adaptation to heat strain, and to the whole environment that commonly goes with it, may give rise to a train of symptoms that have been called, among other things "tropical neurasthenia."[1] This syndrome may occur even when there appears to be adequate functioning of all the other systems necessary to deal with heat strain.

Most of the casualties resulting from heat strain can be fitted into one or other of these categories, but, depending on various individual and environmental factors, the clinical picture may be more complicated, and in some cases several aetiologies may be concerned. Many of the syndromes are intimately connected.

This proposed classification is claimed as a useful working compromise between custom and a correct interpretation of the cause of the syndromes. It will later be justified by the consideration of the physiological and pathological mechanisms involved in heat strain, by a review of the different syndromes, and by an analysis of their occurrence in different environments.

Three other syndromes are included in this review: heat oedema, prickly heat, and sunburn. These are usually dismissed as being of minor importance, but this is by no means so in the case of prickly heat, and even sunburn may be dangerous. Heat oedema is of little importance apart from its inconvenience and the alarm it sometimes causes.

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[1] Chapter 7.

CHAPTER 6.

TYPES OF CLIMATE AND ENVIRONMENT IN WHICH HEAT EFFECTS SYNDROMES OCCUR.

Men have to live and work in a very large range of hot environments, both naturally occurring and artificial, and heat effects syndromes may develop in any of them. However, there are two contrasting types of hot environment that can easily be distinguished, the dry (or "desert") and the humid (or "jungle").

Hot dry ("desert") climate.

This is characterised by very high dry bulb temperatures and solar radiation, but there is a definite seasonal variation and several months of the year may be quite cold. There is also diurnal variation even at the hottest time of the year, and it may be quite cool overnight. The sky is usually clear, allowing of free transfer of radiant energy, and the humidity is low. Sudden and severe wind-storms frequently occur, and may be loaded with dust or sand. The terrain is characterised by sparse vegetation, sand and rocks, allowing for little protection from the heat, and increasing the effects of radiation. The Sahara desert, Central Australia, the desert region of Arizona and California, and parts of the Middle East and Northern India, are representative of this type of climate.

The /

The stress imposed on the body in the attempt to maintain thermal equilibrium in this type of climate is directed mainly on the sweat glands. During the day the air temperature is constantly much higher than the body temperature, and so heat cannot be lost by means of conduction, convection and radiation, all of which processes will on the contrary probably add heat to the body. Sweating alone must therefore remove all metabolic as well as accumulated environmental heat. Overnight, however, when the dry bulb temperature is well below the body temperature, heat may be lost without resource to sweating. The clear sky will allow of considerable cooling by radiation, and blankets may be required for comfort. Hot winds may considerably increase the heat stress on the body, and even when sweating is occurring at very high rates the skin will still feel dry, as the low humidity and high air movement allow the evaporation of moisture as fast as the body can sweat. This may, of course, lead to the false impression that active sweating is not occurring.

As, even when sheltered from the sun, heat is added to the body it is obvious that suitable clothing will reduce the heat stress. Considerable experimental work has been carried out in order to discover the best practical clothing for such climates, but little improvement seems to have been made on the single loose fitting wool robe worn by many of the inhabitants of such countries, although this of course is not practical for Europeans, especially under military conditions. Clothing should have the following qualities: it should act as a barrier to radiant heat; insulate against conductive and convective heat; control air movement in /

in such a way as to reduce heat gain by conduction and convection but not impair air movement necessary for the maximum evaporation of moisture; and it should not inhibit evaporation. Overnight, when there is little danger of heat stress, insulating clothing may be necessary.

Hot humid ("jungle") climate.

This is characterised by relatively low dry bulb temperatures (rarely above 90 deg.F.) and solar radiation, but relatively high humidity. While in some areas there is considerable seasonal variation and several months may be quite cool and dry, more characteristic is the constancy (having the effect of monotony) of climate. Also, there is relatively little diurnal variation, especially during the hotter part of the year, and the night may be even more unpleasant than the day. The sky is often clouded, and there are frequent heavy showers, although these seldom give relief, the cooling effect being neutralized by the increased humidity. Wind velocities are usually low, except for occasional storms. The terrain is characterised by heavy vegetation which serves to retain the moisture.

While areas having this type of climate are much less clear-cut than those with the desert type of climate, parts of India, Malaya, and Central America are typical. Karachi, in spite of being on the edge of the Sind desert, is an example of a city that has a "jungle" type of climate in the summer.

The stress imposed on the body in its attempt to maintain thermal equilibrium is somewhat different in this type of climate. The transfer of /

of heat by radiation and convection is nearly always away from the body and sweating is unnecessary while at rest; shelter is often available as protection when the heat transfer is the other way. Evaporative cooling, when required, is limited by humidity of the air, and air movement becomes an important factor in allowing heat loss. Nevertheless, the climatic conditions are sometimes such that, because of the absence of diurnal variation, uninterrupted sweating even at rest may be necessary for weeks on end. The high humidity and absence of wind overnight under these circumstances result in considerable discomfort, and the skin is continually wet. This may, of course, lead to the false impression that a great deal of salt and water is being lost through sweating, although it is really much less than in the desert (Molnar et al.,1946, Ladell,1945a).

It is obvious that the very minimum of clothing is indicated for this type of climate, and from the point of view of heat stress, nudity is ideal. The latter is, of course, not practical, as, apart from convention, protection must be afforded against insects and local trauma of the skin, and under military conditions camouflage may be important. Considerable research has resulted in the design of the optimum type of clothing for this climate. Thinness is obviously of greater importance than porosity.

The importance of different types of climate.

It is obvious that the body will react differently in these two types of climate, and failure to maintain thermal equilibrium will vary in its cause and in its sequels. It is therefore to be expected that the incidence of the different types of syndromes directly due to the effects of environmental heat will vary according to the type of climate. Circulatory disturbances (showing themselves as "heat collapse", and as syndromes short of actual collapse) will occur in both types of climate. Classical "heat stroke" and syndromes due to water and salt deficiency will be frequent in hot dry climates, rare in humid climates. The unrelieved sweating and continually wet skin associated with humid climates will result in different effects on the skin and sweat glands from the intermittent (though more profuse) sweating and continually dry skin of desert climates. A slight degree of impairment of sweating will be more likely to lead to symptoms in a desert climate, while complete cessation of sweating might even be compatible with life in a humid climate.

All hot countries do not have either one or the other of these two distinct types of climate, and considerable mixtures occur. It should nevertheless be possible to correlate the pathological effects of environmental heat with different climates, and in some instances, with different parts of the world.

Artificial hot environments.

Artificial hot environments may simulate one or other of these two types /

types of climate. For example, steel foundries may have a very high dry bulb temperature and high radiation temperature, with a relatively low humidity; stokeholds of ships, very high dry and wet bulb temperatures; and some deep mines a relatively low dry bulb temperature but very high humidity. The heat effects syndromes occurring in these different environments would be expected to vary in a similar way to those occurring in different climatic environments.

Measurement of environmental conditions.

Care must be taken in interpreting the effect of environment when it is measured by meteorological data from a station that may be many miles away, and perhaps even at a different altitude. In a hot climate local radiation temperatures may be extremely important, much less so in a humid climate. The latter observation was confirmed (personally) at Karachi in the last week of June, 1947, using the methods described by Bedford (1946). Direct measurement in a barrack-room showed that the corrected effective temperature did not differ by more than 2 deg.F. from the effective temperature calculated from the dry and wet bulb temperatures on the airfield outside, ignoring the radiation temperature and assuming that the air movement was nil. This result warranted an approximate calculation of the effective temperature at Karachi itself from the data recorded at the airfield, but this would not apply under all circumstances.

Official meteorological data will not accurately represent the immediate environment of the body when a mosquito net is used at night, as this /

this will interfere considerably with air movement. At Karachi in 1947 (personal observation) simultaneous measurements at night showed that the corrected effective temperature within a mosquito net was 1-2 deg.F. higher than outside the net in the barrackroom, due to the diminished airflow within the net (23 ft. per min.) as compared with the room (130 ft. per min.). The air velocity at the airfield at the same time was of the order of 2000 ft. per min.

Also, according to Shickele (1947), in the immediate environment of the body air temperature is raised 3-4 deg.F. and wind velocity reduced 40 per cent., as compared with meteorological data obtained under standard conditions, while the vapour pressure of water remains unaltered. The importance of "microclimates" has recently been discussed by MacFadyan (1949) who quotes Geiger (1942) as stating that the daily difference in temperature between Assuan, in the Libyan desert, and Alexandria, on the shores of the Mediterranean, is frequently exceeded by that between the actual ground surface and the air a few feet above it in the same meadow, anywhere in Europe. The methods of measuring environmental conditions is discussed at the end of chapter 2.

CHAPTER 7.

HEAT EFFECTS SYNDROMES.

(A) HEAT HYPERPYREXIA AND HEAT STROKE.

Terminology.

The term "hyperpyrexia" is usually employed arbitrarily when the body temperature rises above 106 deg.F., and levels much above this, especially if prolonged, are not compatible with life. When the temperature is rapidly elevated artificially, as by electrically induced methods or by immersion of the body in a hot bath, there may be considerable distress in the form of restlessness and breathlessness until the new level is established, the degree of the distress being related to the rate of rise of body temperature.

Temperatures above 106 deg.F. may result in profound disturbances which show themselves in dramatic clinical events, and justify the illustrative title usually given to this syndrome - heat stroke.[1] The clinical picture of heat stroke supervening on an acute pyrexial illness (such as malaria) is very similar to, if not identical with, that due solely to environmental conditions. It is obvious that a pyrexial illness will be more likely to be complicated by hyperpyrexia and heat stroke when it occurs in a hot environment. While the syndromes are similar, it /

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[1] In the series of 44 civilian cases of "heat stroke" described by Ferris et al.(1938) 9 had temperatures between 104 deg.F. and 106 deg.F. and these were conscious and did not appear to be extremely ill; the remainder had temperatures varying from 106 deg.F. to 112 deg.F., and were either unconscious or stuporose, and were classified as being severely ill.

it is of value to distinguish between them, and it is proposed that that due solely to environmental causes be called "primary heat stroke" and that superimposed on a pyrexial illness, "secondary heat stroke". Similarly, when there is an extremely high body temperature but without the classical features of heat stroke, it is suggested that the terms "primary hyperpyrexia" and "secondary hyperpyrexia" be used. Because of the frequent occurrence of pyrexial illnesses difficult of diagnosis in tropical climates, it may not always be possible to decide whether disease has made any contribution to the raised temperature.

Confusion with regard to aetiology renders the interpretation of many published analyses of heat effects syndromes difficult. In an analysis of heat effects among military personnel in India, Rogers (1908) admitted that "a few cases of cerebral malaria or other diseases may have crept into the returns". Maclean, in his "System of Medicine", published in 1868, described one of his medical officers as being at a loss whether to call his cases of "insolation" remittent fever or apoplexy, and another acting-surgeon of the regiment as registering his cases as either continued or ephemeral fever, although "he correctly understood their real nature". Since then similar predicaments have undoubtedly faced many others, some of whom may not even have been aware of the real nature of the conditions they were dealing with. The "microbic" origin of heat stroke postulated by Sambon (1898) persisted even after it was discredited by Rogers in 1908, and the exact explanation of the syndrome is /

is still incompletely understood.

Published literature on heat stroke.

An attempt is made below to reconstruct the clinical picture of primary heat stroke, ignoring the descriptions in the standard text-books, some of which tend to be copied uncritically from one to another. Detailed descriptions of cases, based on the personal experience of the author, are contained in some of the older text-books of medicine, such as that of Maclean (1868). Since then the bulk of the literature on heat stroke has resulted from the high incidence of heat effects in Mesopotamia (now Iraq) among British troops in the years 1915 to 1917. Willcox and Hearne apparently had the widest clinical experience with these cases and published comprehensive papers on the subject (Willcox, 1920, Hearne, 1932). Although Hearne did not publish his full observations until 1932 he made important observations in the British Medical Journal in 1919 (Hearne, 1919). Both these observers saw large numbers of cases, and obviously had considerable experience of diagnosis and treatment, and their observations are therefore important. The impression is gained that, of the two, those of Hearne are the more valuable. He appeared to have at the time a clearer understanding of the different syndromes caused by heat, and realized the importance of the cessation of sweating in heat stroke, an observation which was not accepted by Willcox.

Morton (1932) recorded careful clinical observations on 7 cases of heat /

heat stroke in Iraq in 1930, and added 4 in a subsequent paper (Morton, 1944). Other clinical material is provided from military experience by Taylor (1919), Croom (1944), Ladell et al. (1944), Borden et al.(1945), Shepherd (1945) and from civilian experience by Gauss and Meyer(1917), and Ferris et al. (1938). Studies in experimental heat stroke have been made by Hall and Wakefield (1927), Marsh (1930) and Daily and Harrison (1948). Other references are given later.

A short description of heat stroke.

Heat stroke occurs in very hot environments. It is due to the failure of the heat regulating mechanism of the body to keep the temperature within reasonable limits. There are several constitutional and other predisposing factors. Exposure to the sun is important, but not necessary, since the causative factor is heat and not a particular solar radiation. Cases begin to occur when the shade dry bulb temperature reaches 110 deg.F. to 115 deg.F., but the wet bulb temperature and air movement are also important. The incidence increases the longer such high temperatures persist. The critical temperature for unacclimatized civilians is much lower. Cases also occur in such places as engine-rooms and bakehouses, where high environmental and high radiation temperatures are found.

The onset is characteristically sudden, with a rapid rise in body temperature to a height of 106 to 112 deg.F. Premonitory symptoms include reduction in sweating, exhaustion, hyperpnoea, and frequency of micturition and /

and polyuria, and the prodromal period may last for several days before heat stroke supervenes. Sometimes characteristic behaviour disturbances occur, especially when the temperature is mounting rapidly, and there may be maniacal delirium. Coma, stertorous breathing, and convulsions may ensue.

The skin is burning hot and dry all over, and the face flushed and sometimes cyanosed. There may or may not be dehydration and circulatory failure. Unless artificial cooling is vigorously applied death frequently occurs, and the recovery rate is related to the height of the temperature and its duration before treatment is applied. If the body temperature is successfully lowered sweating usually begins again fairly soon, and is apparently normal, but instability of body temperature may remain for several days, with a recurrence of symptoms if there is further exposure to heat. In some cases there may be prolonged neurological sequelae.

Post mortem findings are mainly those associated with intense venous congestion, and there are frequently widespread petechial haemorrhages, but anatomical cause of death can rarely be demonstrated.

Aetiology.

Heat stroke is due to the effect of heat on the body, and not to any particular quality of the rays of the sun. This can be concluded because the syndrome occurs in such places as the boiler rooms of ships, and other places where sunrays have no access, and because cases of heat stroke do /

do not occur at high altitudes although they are nearer to the sun.

The idea that sun rays had a particular effect in causing hyperpyrexia was slow to die, and the scientific evidence against this theory was summarised by Marsh (1930). He described how Aron in Manila found that monkeys exposed to the hot sun died within a few hours, but that if they were enclosed in large well ventilated boxes that allowed sweating of the body, with only the head exposed to the sun, they survived although the scalp temperature rose to 47 deg.C.

Although Longmore and Faynor, in India, realized that the incidence of heat stroke was closely related to waves of atmospheric heat in 1881 (Rogers,1908), various other theories persisted, including the "microbic" one of Sambon (1898), until it was refuted by Rogers ten years later. Nevertheless, Noël Coward was not the last person to persist in the belief that the midday sun had a specific deleterious effect on Englishmen, in the face of scientific evidence to the contrary.

Predisposing factors.

Atmospheric environment.

While a very high atmospheric temperature is necessary for the occurrence of cases of heat stroke the critical level depends largely on the type of subjects at risk. Among acclimatized military personnel in the tropics it appears that cases are unlikely to occur unless the dry bulb temperature is at least 110 deg.F. to 115 deg.F. (Rogers 1908, Taylor 1919, Hutchinson 1926, Hearne 1932, Morton 1944, Ladell et al.1944, etc.) /

etc.), although Wallace (1943) described four cases among soldiers undergoing hard training in America in an area where the maximum dry bulb range was 85 deg.F. to 93 deg.F. with only occasional peaks of 95 deg.F. Among civilians in temperate climates who are unaccustomed to extremes of temperature, heat waves lead to cases when the dry bulb temperature is only 90 deg.F. to 100 deg.F. (Gauss and Meyer,1917) or 100 deg.F. to 106 deg.F. (Ferris et al. 1938). Actual environmental temperatures may, of course, have been higher than the quoted official records. In both circumstances, however, the longer such high temperatures persisted the more cases occurred.

Caplan (1943) stated that no case of heat stroke has ever been reported among native underground workers in the Kolar Gold Fields. During the hot season of 1940 he quoted the mean monthly dry bulb temperature as varying between 99.5 deg.F. and 104 deg.F., and the wet bulb temperature between 83.5 deg.F. and 90.0 deg.F., in the deepest part of the mines (approximately 6,500 ft.). He stated that a dry bulb temperature of 110 deg.F. to 120 deg.F. and a wet bulb temperature of 93 deg.F. to 97 deg.F. was not uncommon in "stopes" and "developmental ends", but here special attention was paid to ventilation. Stenning (1945) stated that, in a study of heat effects during two and a half years at sea in the tropics, he never saw a case of heat stroke, although dry bulb temperatures up to 140 deg.F. were apparently recorded. He was dealing, of course, with well acclimatized and suitably clad naval personnel.

The minimum dry bulb temperature is also important, but much more important /

important is the wet bulb temperature (Rogers 1908, Gauss and Meyer 1917, McKenzie and Lecount 1918, Borden et al. 1945, etc.). The extreme importance of the latter is obviously due to the reduced capacity of humid air to absorb water vapour from the skin under circumstances when adequate evaporation of sweat is the only method the body has of losing heat. While a wet bulb temperature of 85 deg.F. in association with a high dry bulb temperature is usually quoted as approaching a danger level, Moss (1927) quoted Haldane as stating that at one time Cornish tin miners in the Levant Mine remained all day in a wet bulb temperature of 94 deg.F.

Air movement is also important for the same reason, and its influence has been noted by many observers. Absence of air movement is probably an aggravating factor in engine-rooms of ships and in bakehouses where many cases of heat stroke have been reported. Willcox reduced drastically the death rate in cases of heat stroke in Baghdad in the 1914-1918 war by advising their treatment outside in the shade where there was a breeze instead of in "cool" underground cellars (Chapman, 1947).

The reduction of air movement overnight probably contributes to the large incidence of cases of heat stroke that is reported to occur during the periods when the shade temperature is well below the dangerous level (Sambon 1898, Rogers 1909, Morton 1944). Chapman (1947) quoted Wooley as stating that during a forced march in Iraq men were perfectly fit in the heat of the day but during the much cooler night "when they passed through a deep rocky gorge where there was little perflation of air, they went down like ninepins". In the case of men reported to develop heat stroke /

stroke while at rest overnight in tents and on troop-decks of ships, in addition to the absence of air movement, the prevention of loss of heat stored during the day by long wave radiation may also be important.

The effects of wind and humidity are well illustrated by Taylor (1919) who analysed the incidence of heat effects in Iraq in 1917, many of which were obviously cases of heat stroke. 88 per cent. of the 1807 admissions occurred during two short periods when the wet bulb temperature was over 85 deg.F., although the dry bulb temperature frequently exceeded 110 deg.F. at other times of the summer. The usual hot dry Shimal wind failed to appear in 1917, and there was a moist south wind blowing in from the Persian Gulf.[1] Shepherd (1945) in Iraq, also noted the deleterious effect of the absence of wind, and of the presence of a southerly wind which increased humidity.

Increased metabolism.

Next to environment, increased metabolism is the most important factor causing heat stroke. This may be due to physical exertion or to disease. There is no evidence that dietetic factors play any important part, and the differences caused by alterations in diet are unlikely to be crucial. The raised metabolic rate associated with hyperthyroidism could presumably be significant. Experience has repeatedly shown the importance of physical exertion in precipitating heat stroke. It is interesting /

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[1] The reverse occurred in Karachi in 1947, when exceptionally high dry bulb temperatures occurred while there was a hot dry wind off the desert in place of the usual wind off the sea, on account of a meteorological disturbance in the Arabian Sea.

interesting to note that Wallace (1943), and Borden et al.(1945), who were reporting on heat effects (including heat stroke) among soldiers in training, commented on the fact that no cases occurred on Sundays. Ferris et al. (1938) however, stressed that in very few of their civilian cases was work a factor.

Secondary heat stroke has been reported to supervene in pyrexial diseases even in temperate climates, and undoubtedly complicates such diseases as malaria in hot climates. Taylor (1919) commented on the epidemic of sandfly fever that occurred in Basra in 1917 at the same time as the high incidence of heat stroke, and stated that men with sandfly fever and malaria were particularly susceptible to heat stroke.

Chloride deficiency.

As chloride deficiency is necessarily associated with reduction in the body fluids, and proper functioning of the circulatory system (which depends on adequate fluid) is essential for the maintenance of thermal equilibrium, chloride deficiency could be expected to predispose to heat stroke. Since sweating is so important at high environmental temperature there will be a reduction in plasma volume unless the chloride lost in the sweat is replaced, and so the risk of heat stroke is increased. Cases of heat stroke and severe dehydration heat collapse frequently occur at the same time, but, rather surprisingly, the literature indicates that cases nearly always seem to fall into one category or the other: cases of heat stroke are seldom reported as also being chloride deficient (e.g. Ladell et al.,1944). It may be that heat stroke, being more

likely /

likely to occur in those subjects whose sweating is less free, occurs before the development of marked hypochloraemia. The relatively greater degree of hydration in those who have stopped sweating may also be a factor.

Cases of severe dehydration heat collapse occurring at the same time as cases of heat stroke are frequently described as sweating freely in spite of their dehydration, and as having a normal or only slightly elevated body temperature. These two observations suggest that loss of body fluid is probably a relatively insignificant factor in the cessation of sweating occurring in heat stroke. Lee (1940), on the other hand, stated that he gained the impression that dehydration rendered thermal equilibrium less stable, and Willcox (1920) believed that it was an important factor predisposing to heat hyperpyrexia.

Diseases resulting in loss of chloride (because of fever, diarrhoea or vomiting) will presumably have the same effect as excessive sweating, although again the literature does not support this theory, as heat stroke does not appear to occur unusually often in dehydrating diseases.

Lack of acclimatization.

In view of the discussion in chapter 4 it is obvious that lack of acclimatization will predispose to heat stroke, as to all other heat effect syndromes. This is supported by literature from the tropics, and by the nature of outbreaks of the syndrome during heat waves in temperate climates.

Accommodation /

Accommodation and clothing.

The importance of radiation and ventilation in the precipitation of heat stroke obviously has a bearing on accommodation, and considerable pains have been taken to design buildings that minimize the risk associated with these two factors. Shepherd (1945) discussed the relative merits of thick walled buildings and thin walled tents as a result of his experience in Iraq. Ferris et al. (1938) found that the majority of cases of heat stroke in a civilian series lived under conditions favouring an excessively warm environment, such as the top floor of brick buildings covered with flat roofs. Clothing that fails to allow of efficient evaporation of sweat in hot environments may predispose to the development of heat stroke.

Race.

In the tropics even well acclimatized white subjects appear to be more prone to heat stroke than natives. This is a common experience, but few detailed analyses comparing the incidence in different races can be found. Taylor (1919) analysed the weekly hospital admission rate during the hot season of 1917 in Mesopotamia, during which there was a large number of cases of primary heat stroke, but he did not differentiate between heat effects syndromes in the analysis. The total admission rate was about fifty times greater in British troops than in Indian. In 1917 the death rate from heat effects was 21.25 per cent. of the total death rate in British troops, and 3.02 per cent. of the total in Indian troops. Presumably a proportion of the deaths were due to heat stroke. Ferris /

Ferris et al. (1938) found 37 white and 7 coloured cases in their civilian series in a population where the corresponding distribution was roughly three to two.

Sex.

It is difficult to assess whether there is a sex predisposition to heat stroke in view of the relatively small number of women exposed to the risk. Nevertheless, there is an impression that women are less susceptible, and of 158 cases of heat effects (the majority of which were probably heat stroke) admitted to the Cook County Hospital during the heat wave in Chicago in 1916, only 6 were women (Gauss and Meyer,1917). In the civilian series of Ferris et al. (1937) 27 were males and 17 females. The relatively less physical exertion normally undertaken by women is probably an important protecting factor.

Age.

It is to be expected that older people, whose cardiovascular system is less adaptable, and may in fact be diseased, will be more likely to develop heat stroke, and this is supported in the literature. In the military series of Ladell et al.(1944), 9 out of 12 cases were over 30 compared with 40 per cent. over 30 in the whole series of 112 cases of heat effects. Only 7 of the series of 44 cases among civilians described by Ferris et al. (1938) were under 50 years of age. The latter quoted the Metropolitan Life Insurance Company statistics as showing that 75 per cent. of the deaths resulting from heat stroke in America occur in patients

over /

over 60 years of age. Evidence is not available on the incidence of heat stroke in infants and young children, but they are notoriously unstable in their thermal regulation, and are therefore presumably more susceptible than adults.

Individual factors.

There appear to be individual factors influencing tolerance to heat apart from those that can be measured, such as sweating function. Body build is sometimes of importance, and obese people certainly appear to be more prone to heat stroke. Metabolic heat production is directly proportional to the body surface area, and it is possible that heat gain from the environment is relatively greater when there is a large surface area. In obese people the relatively small area from which sweating may take place adds an additional hazard.

Alcohol.

The importance of alcohol in predisposing to heat stroke is frequently referred to. Morton (1944) held this opinion, and in his series of 11 cases only one was a teetotaller and four were chronic alcoholics. Gauss and Meyer (1917), reporting on 150 cases of heat stroke occurring during the heat wave in Chicago in 1916, found that most of the cases gave a history of alcoholism, and concluded from their analysis that alcohol was an important predisposing factor. Seventeen of the 38 patients in the civilian series of Ferris et al.(1938) had consumed "significant amounts of beer or whisky on the day of their collapse and in many cases for several preceding days, though only two were considered to be chronic drinkers, and /

and none showed definite evidence of deficiency disease.

It is not known definitely why alcohol should predispose to heat stroke although Porter and Turner (1915) showed that it depresses the vasomotor reflexes, and many observers that it causes a dilatation of the peripheral blood vessels. Barbour and Bourne (1923) showed that ether renders dogs poikilothermic. Kuno (1934) believed that alcohol stimulated sweating through its central action. The possible effect of alcohol as a fluid is discussed below.

The clinical syndrome of heat stroke.

Sources of information.

Detailed accounts of the clinical aspects of heat stroke appear in the literature relating to cases occurring among military personnel in the tropics, among civilians during heat waves in temperate climates, and among men working in hot environments in industry and mines. Many references have already been given, and there are further descriptions in some of the older text books of medicine, such as that of Maclean (1868). Additional information is obtainable from cases of secondary heat stroke, and in particular in cases of "cerebral rheumatism" (Horne, to be published). A study of these accounts shows that the two types of heat stroke are clinically nearly identical. Few of the accounts are complete in themselves, and there are some important deficiencies (especially observations on sweating) but a fairly complete picture can be drawn by studying all the information available.

Onset /

Onset.

The prodromal period which warns of impending heat stroke may vary from a few days to a few seconds. When the onset is sudden it may be very dramatic, and some of the descriptions are fantastic. Hearne (1932) described three cases occurring in his hut at practically the same moment. "Each of the victims leaped from his bed and rushed madly about the hut in a state of wild delirium colliding with everything in his course." Two of them required several people to control them while they were being cooled down. Such descriptions are common but heat stroke may occur more unobtrusively, and frequently men have been found comatose in their beds, sometimes overnight.

During the prodromal period, whether it is short or long, there may be complaints of exhaustion, headaches, dizziness, dyspnoea, and thirst, and defective sweating may be noticed. Frequency and urgency of micturition and marked polyuria are a common occurrence, and patients who have developed heat stroke in hospital have been noted to visit the lavatory frequently just before the onset of coma. The interpretation of this symptom is discussed in Chapter 8. Willcox and Sachs, in the discussion following the paper by Marsh (1930) described men who showed typical behaviour disturbances (they were dull, irritable, restless, quarrelsome) for several days before the onset of heat stroke. On the other hand, the subject may be perfectly well up to a very short time before the attack.

The /

The acute attack.

During the attack the patient may show only slight clouding of consciousness, or may be at any stage between mild delirium and deep coma. This appears to depend mainly on the height of the body temperature, but the personality of the patient may have some influence. The outstanding features are the extremely hot skin which is dry all over, and the high body temperature. The skin is sometimes so hot as to be almost painful to touch. The rectal temperature usually ranges between 106 deg.F. and 109 deg.F., but temperatures up to 114 deg.F. have been recorded (Gauss and Meyer, 1917). The face may be cyanosed, the veins congested, and the conjunctivae injected. The breathing is unusually rapid, and may be stertorous or even Cheyne-Stokes in character, depending on the depth of coma. There may be involuntary spasmodic movements of the limbs or severe convulsions. Vomiting occurs occasionally. There may be pupillary and reflex alterations depending on the degree of coma. Petechiae in the skin have been described in some cases. Few records of the blood pressure have been made, but it is sometimes raised, and sometimes extremely low. Ferris et al. (1938) studied the circulatory disturbance in 44 cases, 17 of which died. They found on admission no evidence of congestive cardiac failure, even in 8 patients known to have previously suffered from dyspnoea on exertion. In 7 patients in extremis there was a low blood pressure and feeble pulse, but in the other 17 studied the systolic pressure was usually elevated and the pulse pressure wide.

Some cases may recover quickly and have no relapse, some may not recover /

recover completely for several days, and others may relapse into coma and die after apparently progressing well (Malamud et al.1946).

Treatment.

Artificial reduction of body temperature is the only treatment that gives a chance of survival, and as the prognosis appears to depend on the duration of the hyperpyrexia, urgency is paramount. Minutes may count and treatment must be started without shifting the patient unless this is necessary to remove him from a source of heat, or in order to obtain more air movement. The method used depends on equipment available, but probably the most effective is the forced evaporation of cold water from the naked skin, ideally sprayed on and fanned with an electric fan. The application of ice is probably no more effective, but the body can be wrapped in a wet sheet and the fan played on it if water is in short supply. Iced enemata are probably of little value. Immersion in ice water may interfere with other resuscitative measures, but Ferris et al.(1938) claimed greater success with this method.

In view of the associated circulatory embarrassment recumbency is indicated, and if there is evidence of failing circulation, the feet should be raised. Venesection should be done only if there is pulmonary oedema, and oxygen is of value under these circumstances. Lumbar puncture has not met with much success. Pentothal or chloroform may be necessary to control convulsions and allow of cooling measures to be applied. Coramine may be used as a stimulant.

Although there is frequently evidence of peripheral circulatory failure /

failure intravenous saline is seldom indicated, since it may aggravate pulmonary oedema. Plasma would be of more value if restoration of depleted blood volume is required.

Cooling must be controlled by estimation of the rectal temperature at short intervals, and when it has reached 103 deg.F. to 102 deg.F. the rate of cooling should be much reduced. Sudden large swings in the temperature are undesirable, and a fatal outcome possibly due to excessive lowering of the temperature has been reported (Ferris et al.1938). Floyer (personal communication,1947), observed one case develop a rigor when the rectal temperature had dropped from 108 deg.F. to 102 deg.F. in about four hours, following which it rose again to 104 deg.F. Observations must continue to be made until it is ascertained that there is no risk of hyperpyrexia recurring.

Coincidental pyrexial disease must, of course, be eliminated as soon as possible, and treated when indicated. Under conditions when heat stroke occurs such fevers as sandfly and dengue may be common, when, of course, no specific treatment is available, but in an area where there is malaria blood films should be examined immediately. In the absence of a positive result, intravenous quinine should not be given unless there is a reasonable likelihood of cerebral malaria being present, in view of its depressive effect on the circulatory system.

Recovery and progress.

The chance of recovery appears to depend more on the duration of the hyperpyrexia than on its actual height. The more rapid the onset and the more /

more rapid the cooling, the better the response, and the fewer are the sequelae. Morton (1944) stated that if the temperature is over 108 deg.F. for more than two hours, recovery is unlikely, although it is possible at temperatures of 110 deg.F. or even 112 deg.F. if they are present only for a short time. Vomiting during recovery has frequently been observed, and Shepherd (1945) considered this to be a good prognostic sign.

Few observations have been made on sweating function following cooling, which confirms the suspicion that the importance of sweating in relation to the syndrome has been inadequately appreciated. Ladell et al. (1944), however, stated that in most of their cases of heat stroke sweating returned within twelve hours of the onset, in contrast to the very slow restoration in cases of anhidrotic heat exhaustion (their "heat exhaustion" type II"). Hearne (1919) stated that in many of his cases there was absolute suppression of sweating for a week or two after the attack.

The patient should be kept in a cool atmosphere for several days after recovery, as pyrexia is prone to recur. The significance of this in relation to sweating function is discussed below. It is stated that patients may remain abnormally "sensitive" to heat for a considerable time after recovery from heat stroke, but this too may be related to sweating function and not to any particular instability of the thermo-regulatory centre.

Various neurological sequelae have been described, from headaches to marked permanent organic changes, but little detailed information is available. This is probably due to the inadequate follow up of such cases /

cases as they are frequently evacuated to cooler areas and are lost sight of. Willcox (1920) stressed the importance of absent reflexes during coma, and their sometimes prolonged delay in returning. Marsh (1930) stated that the after-effects most commonly observed were attributable to some lesion of the parenchymatous tissue of the brain, and suggested a connection with the demonstration by Halliburton and Mott (1925) that a temperature of 108 deg.F., if long continued, coagulated the globulin in the nerve cells of the brain.

Pathological anatomy.

The literature on post-mortem studies of fatal cases of heat stroke is meagre, but the following are the principal observations that have been made. Rigor mortis sets in very quickly and is very marked, and decomposition of the body occurs early. The heart muscle is hard and usually contracted in systole. The blood is in a fluid or semi-fluid state. Generalised congestion of many of the organs, including the brain, is found, and broncho-pneumonia is sometimes present when death has been delayed. Petechial haemorrhages are frequently seen in the skin, in serous cavities, and in the brain, ventricles, and meninges.

Recent literature includes that of Ferris et al.(1938) who performed autopsies on 12 civilians who died in heat waves in America in 1936. The majority of cases showed evidence of degenerative vascular changes, and broncho-pneumonia was considered to be the cause of death in two, but no anatomical cause of death could be found in the others. Their studies added no new knowledge, except to confirm the susceptibility of older people /

people to heat stroke. Wilson (1940) studied the cardiopathology of heat stroke in four cases (three of them due to artificially induced fever). They found that "the most striking, and probably the actual fatal, mechanism" was "a rather extensive haemorrhage under the endocardium of the left ventricle, especially in the septal wall in the region of the bundle of His". Malamud et al.(1946) reported in detail their observations on 125 fatal cases of "heat stroke". They discussed the difficulty in distinguishing the changes, especially in the brain, from post-mortem artefacts, but believed that the cellular degeneration they observed in the parenchymal cells of the brain (especially in the cerebellum, cerebral cortex and basal ganglia) was due to hyperthermia, whereas the haemorrhages, congestion, and oedema were chiefly secondary phenomena coincident with shock. They too described the frequent occurrence of cardiac haemorrhages, some of which were subendocardial. Petechial and larger haemorrhages were frequently present in subcutaneous tissues and skeletal muscles, and the longer the patient's survival, the wider the dissemination of haemorrhage. Their observations led them to conclude that there are two factors operative in heat stroke - hyperthermia and shock.

Experimental work includes that of Halliburton and Mott (1929) who showed that a temperature of 108 deg.F., if long continued, coagulated the globulin in the nerve cells of the brain. Marsh (1930) studied heat stroke in rabbits, and noted, in addition to other things, multiple petechial haemorrhages in the intercostal muscles and in the ears and skin of the back. Further experiments of his are briefly reviewed in the British /

British Encyclopaedia of Medical Practice Cumulative Supplement (1947), but the full details are not yet published (Marsh, 1947a,b). Hall and Wakefield (1927) concluded from their experimental work on dogs that "the important acute pathological change in major heat stroke, other than that due to the effect of high temperatures per se on the tissues, is a massive increase in lactic acid, with the resulting symptom of acidosis", but this observation has so far not been confirmed.

Observations on sweating in heat stroke.

The difficulty in assessing the degree of sweating present at any particular time is discussed in chapter 11. In a stagnant, hot, humid atmosphere the skin may appear to be damp due to failure of evaporation of insensible perspiration although no glandular sweating can be demonstrated even after the local injection of carbachol. In a well ventilated, hot, dry atmosphere the skin may be perfectly dry although sweat is being copiously secreted. Reported clinical observations on the absence of sweating in relation to heat stroke must therefore be interpreted with care.

In 1934 Kuno pointed out that "we may question whether heat stroke is brought about or hastened by the suppression of sweating, or is simply a phenomenon appearing as a result of heat stroke". There seems no doubt, however, that during the phase of hyperpyrexia, and probably in all cases for a variable period before it, sweating ceases over the whole of the body. The observation of Rogers in his book "Fevers in the Tropics" (Rogers /

(Rogers,1919), is valuable. "On examination during the fully developed attack [of heat stroke] the most noteworthy feature is the intense heat of the skin and its dryness, with no trace of perspiration, even in the sweat producing damp temperature of Calcutta".

Hearne (1919,1932) appears to have been the first to emphasise the importance of a prodromal absence of sweating, and based his views on carefully documented clinical observations on a large number of cases. He concluded that "the essential cause of heat stroke is suppression of perspiration, which invariably precedes the attack for a more or less considerable time". He claimed to have prevented many cases by detecting cessation of sweating before the onset of heat stroke. Willcox (1920) could not endorse Hearne's claim, but there is sufficient subsequent evidence to justify it as being correct. Hearne (1932) injected one-fifth of a grain of pilocarpine in 10 cases, but "not a trace of perspiration could be obtained" although there was increased salivation.

Ferris et al.(1938) carefully questioned 21 out of a series of 44 cases of heat stroke among civilians which occurred during a heat wave in Cincinnati. "Sweating did not appear to be significantly altered during the period of hot weather preceding their illness and also near the time of onset of their symptoms. ..... However, a significant number noted cessation of sweat just previous to the onset of heat stroke. Seventeen patients volunteered the information that they ceased sweating at this time. None of the patients gave a history of excessive sweating at the onset". One patient, admitted semi-comatose with a rectal temperature /

temperature of 108 deg.F., was noted to have a dry skin, but he sweated spontaneously and improved before any treatment was instituted. All of the 44 cases had a dry skin on admission.

When evaporation of sweat in a hot environment is insufficient the body temperature rises until at some critical level the thermo-regulatory centre appears to be deranged, hyperpyrexia develops, and sweating is not restored until the body is artificially cooled. It has been shown earlier that the reduction in sweating necessary for this catastrophe to occur varies considerably, depending on the particular environmental and other circumstances.

It is not necessary to postulate in every case a "fatigue" of sweat glands. Even at a normal rate of sweating sufficient increase in environmental temperature or in metabolism, or a reduced efficiency of evaporation, may precipitate heat stroke. Nevertheless the phenomena of fatigue of sweat glands has been demonstrated experimentally and must be considered as a possible factor (see below).

It is important to realize, however, that even a slight reduction in effective sweating may be sufficient to precipitate hyperpyrexia in a very hot environment. It is conceivable that although the skin is always described as being extremely hot and dry in heat stroke, sweating may still be occurring, but evaporation being so effective at the high skin temperature it may not be detected by the eye or hand. The observation that sweating returns so soon after cooling in many cases tends to support this possibility.

However /

However, many cases are reported as giving a clear history of sweating having stopped for variable periods before the onset of heat stroke. For example, in a series of Ladell et al. (1944), in 11 out of 12 cases "sweating had stopped over a period varying from three days to half an hour before the attack". The observation that, following cooling "sweating was in most cases returned within twelve hours of the onset" is difficult to interpret, when in some of the cases it had been absent for several days. Also, in 10 out of 12 cases of "borderline hyperpyrexia" (in which the average rectal temperature was 104.8 deg.F.) "the skin was dry on admission but sweating was quickly restored with immediate recovery". Why should cooling after an episode of hyperpyrexia following cessation of sweating, sometimes for several days, restore sweating? In these cases of Ladell et al., which occurred early in the summer, before many cases of anhidrotic heat exhaustion (heat exhaustion, type II) had developed, "the skin appeared normal, and prickly heat was not severe". Kuno (1934), commenting on the early return of sweating in cases of heat stroke suggested an "inhibition" rather than a "fatigue" of sweat glands.

There seems no doubt that in heat stroke sweating is absent <u>all over</u> the body, including the forehead and face. Characteristically the forehead and face are spared in anhidrotic heat exhaustion, and sweating from this area is frequently excessive and contrasts with the dry skin elsewhere. In one case of anhidrotic heat exhaustion at Karachi, however, (the most severe one in 1947, and in which return of sweating was longest delayed), sweating was absent from the forehead and face even on exposure to /

to severe heat stress.

Injections of diluted carbachol into the skin of patients in the early stage of febrile diseases when the skin was hot and dry resulted in local sweating.[1] Hearne (1919) produced profuse sweating in "ordinary fevers if sweating was not already evident" by a subcutaneous injection of pilocarpine. "In heat stroke, on the other hand, pilocarpine is powerless to produce sweating, though copious salivation takes place". It would be of value to note the effect of local pilocarpine or carbachol in cases of heat stroke.

Decline in sweating rate.

Several investigations have confirmed Haldane's (1929) observations that the rate of sweating declines after several hours of work in a very hot environment. Gerking and Robinson (1946) observed a steady decline in rate of sweating during six-hour experiments with men (maintained in water balance by drinking 0.1 per cent. saline) working in hot environments. It occurred only at high rates of sweating and was distinctly greater in humid than in dry heat. Kuno (1934) and Ladell (1945a) had observed a similar decline in sweating rate in their experimental subjects. Robinson and Gerking (1947) showed that the decline was associated with elevation of skin and rectal temperatures, also more marked in humid heat. In some of their cases they stated that heat stroke would have occurred soon if the men had been forced to continue working beyond six hours.

Since /

[1] Chapter 11.

Since it has been shown that men are more able to continue working in the heat if fluid lost in sweat is regularly replaced, it may be that adequate hydration predisposes to heat stroke, if in fact the sweating rate declines while they are able to continue working. If, on the other hand, they are dehydrated, circulatory collapse may occur before hyperpyrexia can develop. This would explain the common observation that, under conditions in which both heat stroke and severe chloride deficiency would be expected to occur, cases tend to fit into one or other category and are rarely mixed: cases of dehydration collapse are sweating freely and have relatively normal temperatures, cases of heat stroke are anhidrotic and appear to be rarely dehydrated. In other words, a degree of dehydration may precipitate circulatory collapse before the body temperature reaches a dangerous level.

(B) HEAT CRAMPS.

Historical.

The historical aspect of heat cramps was reviewed in detail by Talbott (1935). It was only during the last quarter of the nineteenth century that the syndrome was recognised as being a direct result of exposure to heat, and the first reference to this association appears to have been by Myers in 1897. A depletion of salt and water as a possible cause was first considered by Stone in 1898 (quoted by Fiske,1913), who recommended treatment with hypodermic saline solution. Various other theories were propounded, including degeneration of the muscles and infection. Edsall (1908), in America, described how physicians were aware that the condition occurred frequently at sea and was associated with a certain mortality, but they seemed to be quite indifferent to it, and, because of its common occurrence in the firerooms of vessels, it was thought to be peculiar to the effects of heat at sea. As well as in the tropics, cramps have been described in temperate climates (in iron foundries and in boiler rooms of ships), and the relation between heat cramps and salt deficiency was established in this country by Moss in 1923 when he was investigating the effects of environment on workers in deep mines.

Clinical /

Clinical syndrome.

Talbott (1935) described heat cramps as painful spasms of the voluntary musculature following muscular activity at a high temperature. Although the syndrome of heat cramps may be well illustrated when there is excessive sweating during exposure to a hot environment, the same syndrome may occur in a normal environment when there is salt deficiency due to such conditions as vomiting and diarrhoea, and especially in cholera. In fact, Rogers (1909a) was one of the first to demonstrate the dramatic relief of severe cramps afforded by intravenous hypertonic saline, when treating patients with cholera.

The causative factors of heat cramps are discussed in detail below, but the syndrome does not occur in the absence of salt deficiency. The cramps are more prone to occur, and are always most severe, when there is associated physical exertion, the muscles most used tending to be the most severely affected. The symptoms range from the simple fasciculation of a few muscles of the leg to the excruciating agony associated with severe cramp of large muscle groups, including those of the abdomen. Detailed descriptions have been given by experimental workers (including Talbott, 1935, McCance, 1936, Ladell, 1949), by clinical observers (including Moss, 1923, Stenning, 1945), and by fictional authors (such as C. J. Cutliffe Hyne, in "The Little Red Captain"). They may occur with abrupt and dramatic onset (Heilman and Montgomery, 1936). The cramps are always rapidly relieved by the intravenous administration of saline, more slowly when it is administered by mouth.

Aetiological /

Aetiological theories.

Experience in the deep mines at Pendleton led Moss (1923) to conclude that cramps were produced when unsalted water was drunk while there was salt deficiency, and especially during hard physical work. Haldane, in the discussion of Moss's paper, read to the Royal Society, stated that the miners in Cornwall did not seem to get cramps, and attributed this to the moister air and lesser tendency to drink water compared to Pendleton, where the air was dry. (It is probable too that the loss of chloride in the sweat was greater in the hot, dry atmosphere.) At this meeting he propounded the theory of "water poisoning" as the cause of heat cramps. This was elaborated by Hancock et al. (1929), who postulated that, during physical exercise, when salt was lost in the sweat and water drunk freely, an alteration of the osmotic pressure of the blood accounted for the symptoms of fatigue and cramp. This alteration in osmotic pressure would arise because, although under ordinary conditions the body is able to maintain a more or less constant concentration of salt, MacKeith et al. (1923) had shown that during physical exertion the kidneys excrete very little water. This corresponded to the clinical experience that cramps occurred most commonly in those undertaking severe physical exertion. Caplan (1943) described one subject working in a hot deep mine who developed cramp as an isolated symptom after drinking ten pints of unsalted water during a double shift.

Dill (1936), however, claimed that "water intoxication" did not exist, because, even in severe cases of heat cramps, no unusual departure from /

from normal was found when the serum osmotic pressure was measured directly. Values after recovery were frequently lower than when the cramps were maximal, and complete relief of symptoms occurred when 0.9 per cent. saline was injected, a procedure that does not increase the osmotic pressure of the body fluids. Talbott (1935) also produced evidence that the osmotic pressure is maintained even although certain electrolytes are lost. Dill (1936) also stated that the mechanism of heat cramps did not seem to be a question of sodium-potassium ratio, for injections of isotonic $NaHCO_3$ was not a remedy. Talbott (1935) could not relieve cramps in each of four patients after the intravenous administration of 3.0 to 7.0 g. $NaHCO_3$. These observations suggested that the loss of chloride rather than the sodium ion is responsible.

Caplan (1943), discussing "heat collapse" in native underground workers in the Kolar gold fields, found difficulty in correlating the incidence of cramps with plasma chloride estimations. While his figures suggested on the whole a greater degree of chloride deficiency in cases in which cramps were present, findings in individual cases were anomalous, and cramps were not always present in those with a low plasma chloride. Heilman and Montgomery (1936) found their lowest estimations of plasma chloride in cases of heat cramps when investigating a series of heat effects in steel workers, all of whom had levels below the accepted normal.

Ladell (1949) has recently demonstrated that heat cramps are associated with intra-cellular overhydration, but only occur when the chloride content of the body fluid is diminished, but his experimental technique /

technique is open to criticism on account of inadequate control.

It has apparently been impossible to produce heat cramps in men by overheating alone, although a "cramp-like syndrome" in which tetany appears has been produced. (This is more likely to be due to alkalosis following hyperventilation.) Talbott (1935) quoted McConnell and Sayers (1924) as failing to produce cramps following the ingestion of 900 c.c. of cold water after profuse sweating in a hot room for one hour, but no work was being done. The many experiments during the recent war, in which men were made to undertake vigorous work in artificial hot environments, apparently rarely resulted in heat cramps, but in most of the experiments salt and water lost by sweating was replaced by mouth.

Stenning (1945) stated that the severity of the cramps appeared to depend on the degree of hypochloraemia (assessed without biochemical investigations) and not on the rate of sweating. Epidemics of heat stroke occurring after a few days of extremely high dry bulb temperature do not appear to be accompanied by cases of heat cramps. It is possible that the heat stroke develops before the degree of depletion of salt apparently necessary for the production of cramps can occur.

Talbott (1935) reviewed the evidence on the behaviour of the sweat glands immediately prior to the onset of cramps, and while cases have been reported where cessation of sweating has occurred, he concluded that this was not a regular precursor of cramps.

No definite conclusion can be drawn as to the exact explanation of heat cramps, apart from the fact that there is usually a lowering of the /

the sodium and chloride ions in the plasma, and therefore presumably also in the tissues, and when a critical level is reached, cramps occur. Various factors appear to influence this level, such as individual susceptibility, the degree of physical exertion, and possibly the degree of acclimatization. The common symptom of muscle fatigue short of cramps may be due to a similar mechanism acting to a lesser degree.

Incidence.

Heat cramps can be expected to occur under conditions leading to excessive loss of chloride, and therefore, of course, most commonly in hot environments, and especially where hard work is carried out. They are known to occur in boiler rooms of ships, in deep mines, and in certain industrial establishments, such as iron foundries, where copious sweating leads to loss of salt, unless this loss is made good. Heilman and Montgomery (1936) stated that cases of heat cramps "are seen on any day during the summer months in the first aid dispensary of any large steel mill" (in Pennsylvania). Caplan (1943) reported cramp as a symptom in 142 out of 244 cases of "heat collapse" occurring in native underground workers in the hot and humid Kolar gold fields. The majority of these cases were suffering from varying degrees of hypochloraemia. Gregson (1944) and Hall (1947) have described cases of salt deficiency among civilians in this country giving rise to severe muscle cramps.

In the tropics heat cramps are more likely to occur in the hot dry desert type of climate, but it is difficult to assess their incidence and importance /

importance as a heat effects syndrome. Among reports of large series of cases of heat effects, Morton (1944) stated that cramps occurred in 20 per cent. of his 30 cases of "heat exhaustion". "In severe cases violent cramps in the abdominal and leg muscles are a marked feature of the illness". Ladell et al. (1944) stated that 70 per cent. of 45 cases of hypochloraemic heat exhaustion had heat cramps. Maclean (1943), in an "epidemic" of hypochloraemic heat exhaustion at sea in the tropics, described cases with heat cramps. Borden et al. (1945) mentioned the syndrome, but did not quote figures. Stenning (1945), who made a special study of salt deficiency states during two and a half years at sea in the tropics, described 10 cases of heat cramps (with the highest incidence among stokers) among 120 cases showing clinical salt deficiency states. Rogers (1908), Hearne (1932), and Shepherd (1945), who also described large series of cases of heat effects in the tropics, did not mention the syndrome.

Differential diagnosis.

The possible confusion of heat cramps with tetany should be borne in mind, since tetanic contractions of the hands and feet may follow prolonged hyperventilation. This has been observed by Wingfield (1941), Maclean (1943), and by the author, in cases of hypochloraemia. Carpo-pedal spasm was noted in 6 out of 95 cases of "heat exhaustion" (which were probably not markedly chloride deficient) by Wallace (1943). They were found to have a CO_2 combining power of the blood which varied between

70 and 112. Cramps due to chloride deficiency and tetany due to alkalosis may of course occur together. Caplan (1943), in the series quoted above, noted 3 cases with carpo-pedal spasm in addition to cramps elsewhere. Hyperventilation leading to tetany is more fully discussed in chapter 8.

(C) HEAT SYNCOPE.

The classical syndrome of "syncope", well known in ordinary environments, may occur, and is indeed more prone to occur, in hot environments. In view of the long-standing association of "syncope" with a well recognized and clear-cut syndrome, it would appear to be wise to retain the term "heat syncope" for this syndrome when it occurs in a hot environment, which definitely acts as an aggravating factor.

Prolonged maintenance of the erect posture without movement, and emotional strain, such as that engendered by pain, fear, or disgust, are the commonest causes of syncope. The typical warning symptoms and signs vary in their intensity and duration, and usually consist of dizziness, nausea, discomfort, apprehensiveness, and a feeling of impending collapse, and eventually transient clouding of consciousness. The subject becomes pale, sweats freely, breathes more deeply, and may even yawn, and the blood pressure steadily falls, accompanied by a rapid weak pulse. The final collapse is usually sudden, and the heart may slow. There is usually rapid recovery after a short time in the horizontal position.

It is assumed that an inadequate return of blood to the heart is the cause of the orthostatic hypotension, which leads to cerebral hypoxia. This is caused partly by the pooling of blood in the lower limbs /

limbs (especially if there is no movement) and in the splanchnic area, and is aggravated by the tachycardia shortening the diastolic filling time of the heart. The early signs and symptoms indicate overaction of the sympathetic nervous system, presumably in an attempt to cause vaso-constriction in order to overcome the impaired venous return, and the bradycardia of the collapse stage indicates vagal overaction.

It is obvious that on exposure to heat, when there is marked peripheral vaso-dilatation, the tendency to syncope will be greatly increased, especially in the absence of good acclimatization, as an accurate co-ordination of the vasomotor system is required to maintain the circulation. There is also evidence to show that hyperventilation may accelerate the fall in blood pressure in subjects with postural maladaptation (Engel et al. 1947). As hyperventilation occurs under some circumstances on exposure to heat, it may act as an aggravating factor.

Syncope is more common on the barrack square in the tropics than at home, and this is probably the syndrome that has been referred to frequently in the past as "sunstroke", because of its high incidence among men standing in the sun. Rogers (1908) called such acute syncopal attacks "sunstroke proper", to avoid confusion with "heat stroke". It is interesting to note the significantly higher rates of fainting among blood donors in the Middle East described by Buttle (1945, quoted by Barcroft and Edholm (1946).

The subject has recently been studied by Horvath and Botelho (1949) in subjects immersed in a hot bath. Other investigations have shown that /

that the tendency to this type of syncope can be reduced in normal environments by adequate physical training, and in hot environments by adequate acclimatization.

It is not surprising that few clinical reports of this syndrome are to be found in the literature, and that it seldom appears in analyses of cases of heat effects, as the condition, though probably of common occurrence, is mild, is recovered from rapidly, has no important sequels, and rarely results in admission to hospital.

A similar syndrome occurs in men working or marching in the heat, and especially when the erect posture is assumed and maintained after such exercise. The name "circulatory heat collapse (exercise precipitated)"[1] is preferred for this.

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[1] Chapter 7.

(D) HEAT EXHAUSTION AND COLLAPSE.

On exposure to heat, and especially when work is done, symptoms of exhaustion of all degrees up to and including actual collapse may develop. The severity of symptoms depends principally on the degree of heat strain to which the subject is exposed.

Several symptoms are common to all types of heat exhaustion - a vague feeling of discomfort and unpleasant warmth, irritability, restlessness (or occasionally drowsiness), muscle fatigue and an inclination to sit or lie down, headache, dizziness, palpitations, breathlessness, and slight nausea. Different combinations of these, and different degrees of severity, may be present depending on circumstances. For example, when there is anhidrosis, the undue feeling of warmth may be very prominent, probably due to the relatively high skin temperature, and there may be marked hyperpnoea and polyuria; when there is severe dehydration muscle fatigue may be very prominent.

As the heat stress continues or is increased these symptoms become more and more severe, until collapse eventually occurs. At the point of collapse the subject may be very distressed, there is marked tachycardia, breathlessness, some clouding of consciousness, and usually some elevation of body temperature. The degree of sweating will vary, and may, of course, be /

be completely absent except on the face in anhidrotic heat collapse. Depending partly on the body and skin temperature there may be considerable hyperpnoea. In some cases, especially in circulatory collapse without severe dehydration and without anhidrosis, there may be bradycardia immediately after collapse, and the clinical picture resembles classical syncope. Recovery is rapid after resting and cooling except where there is marked dehydration, when symptoms and signs of peripheral failure persist until the body fluids are replaced.

Symptoms will be attributable fundamentally to failure of the circulation and to accumulation of heat, and it may be difficult to apportion them, although some symptoms may predominate, depending on which system is principally at fault. The importance of the contribution to symptomatology made by hyperpnoea itself is discussed more fully in chapter 8.

Circulatory heat exhaustion and collapse (exercise precipitated).

This syndrome is seen most clearly in men marching or working hard in the heat, and has been described both in the field and in experiments in artificial hot climates. Dehydration, if present, will obviously contribute to the syndrome, and it may not always be possible to determine to what extent it is responsible except under carefully controlled conditions.

Symptoms of exhaustion may be present even at rest, but are more prominent during physical exertion. Characteristically they become worse as work progresses until the subject has to give up voluntarily or until he collapses. Often the symptoms may be slight until he rises to the erect /

erect position after stooping, when sudden collapse may occur. The symptoms, including the clouding of consciousness associated with actual collapse, are rapidly relieved on resting, especially if recumbent. Delay in recovery, with evidence of persisting circulatory failure, is presumptive evidence of dehydration, and such cases may present the picture of dehydration heat exhaustion on collapse.

The degree of elevation of body temperature present will depend on many factors, but principally on details of the environment, and on the state of sweating function at the actual point at which heat strain was reduced. For example, a well acclimatized man with impaired sweating function in a really hot environment might be able to continue working until his rectal temperature reached a considerable height, whereas a poorly acclimatized man in a cooler environment might give in, and even collapse, long before there was time for such elevation of temperature to take place.

Weiner (1938,1949) studied the syndrome in native subjects working in the hot humid mines of South Africa, when no observations were made on possible chloride deficiency. Caplan (1943) made a similar study, and showed that in some cases chloride deficiency probably contributed to the collapse. Dreosti (1949) observed cardiovascular collapse resembling an ordinary fainting attack, and as quickly recovered from, in native labourers subjected to a heat tolerance test involving shovelling rock in a very hot environment. Brown (1947) studied the syndrome in a staged experiment with volunteers in the American desert both with and without dehydration. /

dehydration. Its occurrence in environments in which salt deficiency syndromes are also common is illustrated by the study of cases of "heat disease" in steel mills in America by Heilman and Montgomery (1936) and Collings et al. (1943). Experimental studies in artificial environments include those of Scott et al. (1940) and Eichna (1947) (quoted by Machle and Hatch, 1947).

These authors and others describe the syndromes they encountered in considerable detail, and the following extract from a report by Wallace (1943) illustrates the syndrome as it occurred among soldiers in training at a station on the Gulf of Mexico. Between June and September, when all the cases of heat effects occurred, the maximum dry bulb temperature ranged between 85 deg.F. and 93 deg.F., with occasional peaks of 95 deg.F., and the minimum temperature between 70 deg.F. and 73 deg.F., with occasional peaks of 80 deg.F. No data were provided about the humidity or wind. An attempt was made to ensure that all the men were adequately hydrated during the summer following the occurrence of the first few cases. In all, there were 4 cases of heat stroke and 95 cases of "heat exhaustion" (12 of the latter occurred in one squadron following a march of six miles wearing raincoats).

> "The 95 cases all had the same characteristic clinical picture. The cases with a normal temperature were the mildest, and those with higher admission temperatures were more severe. The height of the admission temperature and severity of the disorder were in direct proportion. The general picture was as follows:- Many noted weakness and malaise one or even two days preceding the onset. On the day of the attack, while on the drill field (43), the weakness became marked (68), with profuse perspiration. Some became nervous (14), and would cry or become light headed (19). Many became dizzy (38) or would develop headache (32). Most felt that they would faint and many (47) did. Of these latter 6 were still unconscious /

"unconscious on admission to the wards. A certain number became nauseated (28), although only half of these vomited (13). A few had mild abdominal or leg cramps (9), or a feeling of numbness (6), and a few had temporary blindness (4), or dyspnoea (3).

"Physical examination on admission showed the pulse and respiration to be normal when the temperature was normal, and slightly elevated when the temperature was elevated. The blood pressure readings were normal. The skin was moist but not clammy and perspiration was marked. There was no pallor unless the faint had just occurred. The lowest admission temperature in the entire series was 97.6. In no case was there a picture that in any way resembled a condition of shock. Many cases were mentally sluggish and could not cerebrate well. Nine cases had muscular twitchings and six had definite and marked carpo-pedal spasm. With rest, fluids, salt and an increased attempt at evaporation in those with a higher temperature recovery was prompt and practically all had a normal temperature the following day.

"Adequate laboratory studies were impossible in all cases. The findings in those in which laboratory studies were made were constant: moderate elevation of blood urea, normal blood calcium, normal blood chlorides, normal to slightly reduced cell volume, normal R.B.C.,Hbg. and negative urine."

This is probably the syndrome called by several observers "subacute effects of heat", and its most illustrative title might be "exercise precipitated heat exhaustion (or collapse)".

Dehydration heat exhaustion and collapse.

The effects of water and salt depletion have recently been reviewed by Marriott (1947). The exact effects depend on the relative deficiency of each substance, which will in turn depend on many factors, including the mode of loss and the amount of each replaced. In a hot environment pure water deficiency occurs only under very special circumstances (such as men lost in the desert or ship-wrecked at sea), and salt deficiency is, of course, much more common. This arises most often from excessive sweating /

sweating, and may be aggravated by diseases, common in tropical countries, that lead to vomiting and diarrhoea. The principal effect is an extracellular dehydration, and there may also be a disturbance of the acid-base equilibrium, but the latter is relatively unimportant.

High sweating rates are found principally in very hot environments, and occur especially when work is being done. When it is realized that in desert climates men frequently lose as much as 8-10 litres of sweat containing up to 20 g. of salt in twentyfour hours, enormous deficiency can develop unless there is adequate replacement.

Chloride deficiency leads to many characteristic symptoms and signs, which are, of course, the same whatever the cause, and which vary in severity according to the degree of deficiency. There are many factors contributing to the feature of "exhaustion" - lassitude, asthenia, apathy, actual muscle weakness, headaches, giddiness and tendency to fainting. Anorexia may progress to nausea and even to vomiting, and this, of course, starts a vicious circle due to further loss of chlorides from the stomach.

Thirst is not prominent. While it is believed that some animals have the ability to distinguish between the desire for water and salt, man does not, and so salt deficiency cannot be judged by the desire for this substance. Pure water depletion is accompanied by a sensation of thirst and so is usually corrected, but water depletion secondary to salt depletion can proceed to considerable lengths and with quite gross physical signs without the desire for the replacement of either. Marriott (1947) stated that he had seen men in the tropics refuse water or spit it out even when they /

they were suffering from severe secondary dehydration. It has been noticed, however, that saline is sometimes less nauseating to take, even in high concentrations, when salt deficiency is present (Stenning, 1945).

The dehydration shows itself in the sunken eyes, dry tongue, and loss of elasticity of the skin. Many patients are aware of a reduction in the urinary output, and oliguria is nearly always observed, with a diminution or complete absence of urinary chloride. There is a fall in the plasma chloride and sodium, and the blood urea rises and plasma volume falls. If there is much disturbance of the acid-base balance the alkali reserve will be altered.

If there is much reduction in plasma volume the pulse rate rises, the blood pressure falls, and the picture of dehydration (hypochloraemic or oligaemic) circulatory failure is present. This condition has led to a proposal that the syndrome should be called "heat shock". If salt and water are not replaced, the condition deteriorates. The patient becomes pale and has a "clammy" skin, the pulse becomes more rapid and the blood pressure falls, and consciousness is gradually lost. Vomiting is common (in 73 per cent. of 45 cases in the series of Ladell et al. 1944). Hysteria and sometimes extreme excitement may occur before eventual coma, and hyper-ventilation (which is often at least partly hysterical) may lead to tetany. Death may ensue unless the blood volume is restored rapidly.

The clinical condition improves more or less rapidly, depending on the severity, after the administration of intravenous saline, although extreme oliguria and complete absence of chlorides from the urine may persist /

persist for a considerable time after treatment has started.

The mental disturbance associated with chloride deficiency, and the simulation of psycho-neurosis is further discussed later under "tropical neurasthenia". Heat cramps have also been discussed separately.

Alimentary symptoms due to salt deficiency.

There appears to be no doubt that salt deficiency may be directly responsible for prominent gastro-intestinal symptoms, and indeed many classifications of heat effects have in the past included the "choleraic", the "gastric", and the "gastro-intestinal" types. While these classifications may be justified on the grounds that they indicate the presenting symptoms they tend to be confusing unless it is appreciated that the underlying cause is salt deficiency.

It must be remembered too, especially in the tropics, that alimentary symptoms due to infection frequently occur at times when heat effects are common, and it may be difficult to determine the exact aetiology. Marriott (1947) has discussed the mechanism of vomiting in hypochloraemia, and Moss (1927) stated that experimental heat strain involving complete evaporation of a terrific sweat output, caused vomiting. Many of the accounts of heat effects in the tropics indicate that vomiting frequently accompanies hypochloraemia, including that of Ladell et al. (1944), where there was no doubt about the presence of hypochloraemia. Stenning (1945), who saw many cases of hypochloraemia at sea in the tropics, described dyspepsia and vomiting as occurring commonly, and stated that laparotomies were sometimes done on account of abdominal pain when the actual cause

was /

was salt deficiency.

Diarrhoea has also been stated to accompany salt deficiency states, but is more difficult to assess because of the complicating circumstances discussed above. Outbreaks of vomiting or diarrhoea, or both are reported to occur frequently among troops on the march or in training in the tropics, but even although these symptoms occur during exposure to considerable heat strain it is not always justifiable to attribute them to the specific effects of heat. The circumstances under which these outbreaks occur are usually peculiarly suited to outbreaks of fly-borne and carrier-borne gastro-enteritis and dysentery, and, also because of these circumstances, investigation from this point of view is usually impossible. Sams (1944) states that cases of "gyppy tummy" (subacute attacks of gastro-enteritis that occur frequently in all parts of the tropics, and usually attributed to non-specific causes, such as "chill on the stomach"), were all found to be mild cases of dysentery when it was possible to make surveys. Stenning (1945), however, who was aware of the possible confusion with alimentary infections, took careful measures to eliminate the latter as a cause of the diarrhoea in his cases. It has been suggested that irritation of the smooth muscle of the gastro-intestinal tract by a mechanism similar to that causing cramps of striated muscle may account for these alimentary symptoms.

Anhidrotic heat exhaustion and collapse.

This syndrome was not distinguished from the other effects of heat until 1944, although a study of the literature reveals its existence in earlier /

earlier records, when it was confused with other syndromes. The majority of cases are reported as occurring in humid climates, where it may be the most common heat effects syndrome, and the type of climate may slightly modify the clinical picture. It is critically reviewed in chapter 11.

The syndrome is directly due to impairment of sweating, caused by a peripheral failure of sweat glands, the exact aetiology of which has not yet been determined. The majority of cases give a preceding history of severe prickly heat, and so it is probably related to this condition, and there is histological evidence that has been interpreted to mean that there is a mechanical obstruction of sweat ducts. The glands of the face and neck nearly always escape. Associated with the impaired sweating there is a fairly constant characteristic appearance of the skin which has been called "mammillaria".[1]

Symptoms are directly due to impaired sweating, and the degree of impairment required before they develop depends on the degree of heat strain imposed. Symptoms develop without total anhidrosis in a hot dry climate much more readily than in a humid and not so hot climate. Subjects are usually aware of the reduction in sweating.

In the absence of severe heat strain a train of mild exhaustion symptoms may be present. With increasing heat strain, such as physical exertion or exposure to the sun, the general symptoms become more marked. The subject feels very warm, there is severe hyperpnoea and tachycardia, frequency of micturition and polyuria may develop, there is considerable distress /

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[1] Chapter 12.

distress, and unless the heat strain is relieved, clouding of consciousness and collapse may occur. The hyperpnoea probably gives a considerable contribution to the symptomatology.

On examination, even at rest, there may be unusually profuse sweating on the face in contrast to dryness elsewhere, and this is even more striking when heat strain is increased. Hyperpyrexia and heat stroke are potential dangers, although in most cases symptoms are prominent enough to lead to removal of heat strain before the body temperature is much raised. Symptoms are rapidly relieved when heat strain is removed, and can be reproduced when it is reapplied.

Anhidrosis may persist for many weeks, even after the subject has been moved to a cooler climate, but appears always to return to normal. Those who have recovered may suffer from the syndrome again in a subsequent hot season.

Chloride deficiency does not contribute to the aetiology of the syndrome, but it of course may be present in cases in an area where chloride deficiency occurs. The sweat chloride and the sweat pH are considerably raised.

The diagnosis depends on the demonstration of anhidrosis, which of course need not be complete in certain circumstances in order to result in symptoms. At all stages the profuse sweating on the face in contrast to the dry skin elsewhere is probably the most useful single diagnostic feature. No special treatment is required apart from the removal of heat strain, and vigorous cooling measures are indicated only if the body /

body temperature has reached a dangerous level. There is no known way of hastening the restoration of sweating, and in areas where there is high environmental temperature, it may be necessary to remove cases to a cooler climate. If the anhidrosis is directly due to the changes in the skin associated with prickly heat, as is suspected, then attempts to prevent this condition will presumably reduce the incidence of cases.

(E) TROPICAL NEURASTHENIA.

Prolonged residence in the tropics has long been known to have profound psychological effects of a deleterious type. Cilento (1925), Castellani (1938) and Huntington (1945) have discussed the problem as it affects white settlers in the tropics, and many authors, such as Conrad, Kipling, Somerset Maugham, and H.E.Bates, have employed it for dramatic purposes. Objective observers, such as the late Ian Morrison in "Malayan Postscript", have also contributed to the study.

The background against which these changes take place is now almost legend. With regard to the military population, the opening of the paper by Morton (1944), in which he describes the terrain and climate in Iraq, illustrates some aspects of it for the Army and Royal Air Force, and Critchley (1945) describes the conditions under which naval ratings may have to live in the tropics. Fictional authors have provided the background for the "tropical deterioration" of the more sophisticated civilian life. The syndrome has been aptly attributed to a failure of "accustomization" (Siple, 1949).

There is no lack of evidence of a high incidence of actual psychoneurotic illness in the tropics, and series of cases of this type occurring during the recent war in the Army, Navy and R.A.F. have been described by /

by Lyndsay (1946), Cameron (quoted by Ellis,1947) and Trenchard (1946) respectively. The Americans also found a high incidence of psychoneurotic illness among their troops, and that it was not peculiar to the recent war was shown in the high figures quoted by Woodruff (1905, quoted by Critchley,1945) for their soldiers in the Philippines in 1901 and 1903. Nor are these syndromes confined to military personnel, as was shown by the high incidence of invaliding due to psychiatric disorders in East and West Africa among civil servants, "carefully selected Europeans who had chosen a career within the tropics" (Critchley,1945).

The relationship between tropical environment and psychoneurotic symptoms has been studied on many occasions, recently very shrewdly by Critchley (1945,1947) and Lyndsay (1946). Manson-Bahr, in the latest edition of his "Textbook of Tropical Diseases" (1945), also discusses this question at length. It will obviously be difficult to decide sometimes to what extent these syndromes are due to the specific effects of heat on the human body, and to what extent to all the other factors operating under tropical conditions. For instance, alcoholic and sexual excesses, factors sometimes operative in the production of psychoneuroses even in temperate climates, have been stressed by those who have had long experience in the tropics, such as Manson-Bahr (1945) and Rogers and Megaw (1946), and by some American observers who have had a shorter, but perhaps more concentrated experience (Solomon and Yakovlev,1944, Strecker and Appel, (1945).

One important factor that has probably not been sufficiently stressed is /

is the difficulty of adaptation to the monotony of the climate, rather than to any particular standards of heat and humidity, which is mainly a physiological problem. The Serviceman's phrase "there's too much bloody climate and not enough weather" picturesquely expresses the feelings of many sojourners in the tropics, voluntary or otherwise. As Sundstroem (1927) has pointed out, "very little is known to what extent life processes are dependent in their proper functioning on fluctuations in weather conditions, but everyday experience supports the assumption that such fluctuations are beneficial". Difficulty in obtaining adequate sleep under certain environmental conditions may also be an important factor. It is interesting to note that the majority of the popular names applied to the syndrome ("West Coast memory", Toomey, 1944; "Bengal head", etc.) originate in hot humid areas, where monotony of climate is a characteristic.

The only planned investigation on the contribution made by various possible operative factors in the aetiology of tropical deterioration appears to have been that directed by Macpherson (1949) among Australian and New Zealand military personnel serving in a tropical climate, and this was cut short by the premature end of the war against Japan. The loss of efficiency noted during the relatively short period of observation appeared to be greater than that which could be accounted for by demonstrable physical deterioration, and a large part could be attributed to psychological deterioration. It was concluded that the latter was more due to actual climatic conditions than to other factors, such as boredom, isolation, and the conditions of service generally.

The /

The nature of the syndromes loosely included under the heading of "tropical neurasthenia" or "cacophoria tropicalis" varies considerably, and it is not possible to explain them all psychologically or analyse them physiologically. Nevertheless, a proportion of them are closely related to particular factors associated with exposure to heat, and so, having an "organic" basis should not really be included in the "psychogenic" category.

Certain behaviour disturbances can be attributed more or less specifically to the effects of heat. The following quotation from Sir William Willcox's contribution to the discussion on the paper by Marsh (1930) is an illustration.

> "There were two very interesting types of heat stroke that one saw. One was the type that I called the gastric [sic] type, in which a man exposed to heat would get very irritable and a little flushed. I used to come in contact with these cases, because sometimes one of the administrative officers would come to me and say 'I wish you would invalid so-and-so into hospital; he is such a nuisance in our mess. He is quarrelling with everybody. None of us can get on with him'. I remember some of these cases where men had been irritable and troublesome, and worrying other people. The patient would be sent into hospital. His temperature would be normal for several days, and his heart also. There was nothing to be found wrong with him, except that his face was a little flushed, and there was some mental depression. Then suddenly the temperature would go up to 110°F., and death might occur. I saw several of these cases."

Colonel A. Sachs, in the discussion following the paper of Morton (1944) also spoke about the not infrequent "change in the patient's normal behaviour, e.g. dullness, irritability, restlessness, or even insubordination". This stage would last for three days to three weeks, but usually it was two to ten days before hyperpyrexia developed. Shepherd (1945) also /

also described behaviour disturbances as being characteristic of certain types of what he called "subacute effects of heat", cases in which there was sustained moderate elevation of body temperature. Several observers have noted that irritability and lack of concentration is complained of by patients with anhidrotic heat exhaustion, and indeed some of the cases described by Willcox, Sachs, and Shepherd (referred to above) may have been cases of this syndrome, some of which subsequently developed hyperpyrexia and heat stroke. Gross behaviour disturbances, sometimes of a maniacal type, are frequently described when the temperature is mounting rapidly to hyperpyrexial levels.

The changes in the body associated with acclimatization to heat were discussed in chapter 4, and it is obvious that inadequate adaptation of the cardiovascular system may result in symptoms simulating effort syndrome or cerebral anaemia, as long-continued circulatory insufficiency may give rise to symptoms of a neurasthenic type. The chronic anaemia associated with haemodilution described by Lee (1940) and Sams (1944) may also give rise to similar symptoms. The milder forms of the various heat exhaustion syndromes frequently present as symptoms that can be interpreted as of psychological origin.

Disturbance of salt and water balance can give rise to behaviour disturbances. This has been demonstrated by experimental physiologists - in dehydration after sweating by Bazett (1927), in salt deficiency by McCance (1936,1938), and in pure water deficiency by Black et al.(1944). The last observers noted that their subjects exhibited a change in behaviour /

behaviour which could be interpreted as an exaggeration of their temperamental type. That mental symptoms due to overhydration can occur under certain climatic conditions was demonstrated at Karachi in 1946 and 1947 (Mole, personal communication, Floyer, unpublished data, respectively).

Salt and water deficiency may occur even in the thoroughly acclimatized, and its relation to one type of heat exhaustion and to heat cramps, has been established clinically and biochemically. There is evidence, however, that smaller deficiencies of these substances, or a state of imbalance between them, may lead to symptoms short of the full syndromes, and lead to confusion with psychiatric disease. Undue fatigue in hot environments has been shown to be due to lack of salt in miners by Moss (1923), and in industrial workers by Stewart (1945).

Saphir (1945) maintained that chronic hypochloraemia could simulate psychoneurosis, and cited 10 cases in which symptoms rapidly improved following the administration of salt. Blood chloride levels in these cases were available before and after treatment, and the quantities of salt administered were stated. The increase in the blood chloride levels corresponded with what might have been expected from the quantities of salt administered, but the levels obtained after the clearing up of symptoms were all at the lower limit of range in normal subjects. The clinical results appear to have been impressive, but of course it is difficult to distinguish the specific effects of salt from those possibly due to admission to hospital and relief from other aggravating factors. No indication was given of progress after discharge from hospital. The amounts /

amounts of salt given were small considering the average daily requirement in a hot climate.

Stenning (1945), however, as a result of extensive experience at sea in the tropics, concluded that the symptoms ascribed to "tropical neurasthenia" were frequently due to inadequate replacement of salt lost in the sweat, and illustrated how even the most sceptical could be convinced of this. Whitty (personal communication,1949), as neurological physician to a head-injury unit with the 8th Army in North Africa, found that cases of neurosis without adequate exogenous cause seemed to respond excellently to extra salt. Black (1946) commented on the increased feeling of well-being in patients with chronic sprue after they have been given extra salt. Collings et al. (1943) observed that the effects of heat in factory workers could be measured by reduced work capacity even when not severe enough to cause a recognizable clinical syndrome, and they too found that replacement of a relatively small quantity of salt appeared to have a critical effect. The statement of Sir Josiah Court (1924-25) that the wives of colliers said that their husbands were "more energetic on arriving home" after the institution of the habit of drinking 0.25 per cent. saline at work, may not have been without its psychological implication!

Restlessness, anxiety, hysteria, and mental confusion may be present in dehydration heat exhaustion. Morton (1932) reported one case with maniacal delirium who had to be anaesthetized before intravenous saline could be administered, and who was normal in twelve hours; Shepherd (1945) reported one hysterical case with severe dehydration who died; Maclean (1943) /

(1943) reported a case complicated by tetany from rapid respiration, and the author has seen a similar case in which there was no elevation of body temperature to account for the hyperventilation, which was of the hysterical type.

It has been suggested that vitamin deficiency may contribute to impaired performance and even to psychoneurotic symptoms in a hot environment, although no direct evidence is available. It is true that inadequate vitamin intake may occur in the tropics, especially in military personnel, but Sargent et al.(1944) have established that loss in sweat is not a significant factor in depleting the body's store of water soluble vitamins.

Apart from true psychoneurotic illness standards of "human performance" have long been known to deteriorate under tropical conditions, and, again, many factors contribute their share. The difficulties in assessing to what extent alterations in efficiency are actually due to climatic conditions rather than to the other environmental factors, and the various field researches (both in industry and in the tropics), have been reviewed by Critchley (1947). Recent laboratory work includes that of Weiner and Hutchinson (1945), who studied the effect of a hot humid environment on the performance of a motor co-ordination test, and of Mackworth (1950), who studied the effect of a similar environment on wireless telegraphy and radar operators. Both found impairment of performance, and the latter was able to determine the specific conditions, including the effective temperature, under which a statistically reliable reduction in accuracy /

accuracy first appeared. Some of the effects of this type usually attributed to heat resemble those due to "fatigue" under temperate conditions, and it is obviously difficult to assess the exact contribution made by heat.

Lee and MacPherson (1948) made a large scale statistical survey on R.A.A.F. personnel on active service in the S.W. Pacific area in an attempt to determine the relative importance of physical and mental phenomena in "tropical fatigue". Opinions of the men themselves and of their commanding and medical officers were recorded as to their efficiency in relation to length of tropical service. Various tests were employed to assess the physical condition of the men, and the deterioration noted compared with the reported loss of efficiency. A general lowering of efficiency in tropical areas as compared to base conditions was established but this could not be accounted for adequately by physical effects, and it was concluded that personal and psychological factors were of paramount importance, and that much of the inefficiency was preventible by realistic handling of these factors.

There is some evidence of a higher susceptibility in hot environments to emotional reactions that have organic manifestations. Buttle (1945, quoted by Barcroft and Edholm, 1946) found that the fainting rate in blood donors might be as high as 20 per cent. in the Middle East when the environmental temperature was 100 deg.F. or over. The average fainting rate is usually about 5 per cent. (Poles and Boycott, 1942, Brown and McCormack, 1942). It is difficult to assess to what extent this type of reaction is emotional, especially in view of the alterations in the vasomotor system /

system associated with exposure to heat, but Lee (1940), who noticed a similar high incidence of syncope attending venepuncture in hot environments, attributed it to emotional reactions. Weiner and Hutchinson (quoted by Ladell,1947) found that, on the tilting table, fainting occurred much sooner in the heat although pooling of blood in the legs was no greater than in the cold. It is possible that the sensation of discomfort associated with heat may have an aggravating effect in precipitating syncope. In this respect it is also interesting to note the observations made by Kuno (1934) that at very high environmental temperatures, mental arithmetic caused suppression of sweating!

And so in the assessment of cases presenting in hot climates with psychoneurotic symptoms careful judgment is required. It is important first of all, of course, to eliminate organic disease, and if it is present to assess to what extent it accounts for the symptoms. In the absence of organic disease it is necessary to consider two important things, salt deficiency and sweating deficiency. Possible nutritional deficiency should also be borne in mind.

Salt deficiency can be assessed within limits by simple examination of the urine, and, if possible, the blood, and if there is any doubt, the therapeutic trial of adequate salt by mouth should be tried. It should be realized that the measurement of the concentration of the plasma chloride and sodium is a very inadequate way of judging the total deficiency of either of these, as pointed out by Abbott (1946), because the balancing mechanisms make an effort to maintain isotonicity. The kidneys reduce /

reduce the excretion of water when chloride and sodium are deficient, and plasma volume is reduced in order to maintain the correct electrolyte concentration. The assessment of sweating deficiency is more difficult, but a simple exercise test in the heat should give an indication of the potential sweating power, not only by the amount of sweat produced, but also by the reaction of the patient.

Neurasthenic symptoms may of course occur in subjects very recently exposed to a hot environment, and inadequate acclimatization may be the reason. They are much more common, however, after prolonged exposure, and once an individual becomes physiologically acclimatized to a hot environment there is no obvious reason why he should not remain so, provided he is not removed from it for any length of time. Evidence of failure of acclimatization after prolonged exposure has not been proved, although experimental work suggests that, in so far as a humid environment is concerned, there may be a falling away after reaching the peak of acclimatization (Eichna,Ashe,et al.,1945).

Native populations in the tropics are not exempt from behaviour disturbances related to the climate. The peculiar conduct associated with certain of the hot winds (such as the "Shimal") is an example. Huntington (1945) stated that factory output decreases and riots and assaults increase when the environmental temperature is over a certain level. The "Statesman" (Calcutta) published a graph in 1947 showing the relationship between rioting and peaks of environmental temperature in that year. Caplan (1949) has recently discussed the occurrence of mental fatigue and psychological /

psychological changes in native labourers in India, especially underground workers. He stressed the easy prey to the agitator of the mentally fatigued and apathetic worker, and the reduction in the accident rate after the installation of air-conditioning plants.

The syndrome of tropical neurasthenia is obviously a very diffuse one, and has been used in the past to include a wide variety of conditions. While it is a useful title, care should always be taken before it is applied to any case to eliminate organic causes, and in particular the specific effects of a hot environment, such as salt deficiency and inadequate sweating.

(F) OTHER EFFECTS OF HEAT.

Heat oedema.

This term is applied to the oedema of the extremities, and particularly the feet, commonly experienced in hot climates. It ranges in degree from a feeling of tightness of footwear (or occasionally the watch-strap) to temporarily incapacitating swelling of the ankles and lower legs. It is usually transitory, disappearing with acclimatization, and there is an individual susceptibility. Castellani called attention in 1931 to the relation between this type of oedema and heat, and in 1938 referred to it as "Aden oedema" or "Red Sea oedema", which popular titles indicate its aetiology (Castellani, 1931, 1938).

"Deck ankles" were common among troops in transit to the East during the last war, and Munro (1944) detailed his experience of this condition on a troopship in the Red Sea. One per cent. of the troops (but none of the ship's company or permanent staff) were affected, and all degrees of oedema were noted, from slight puffiness to complete obliteration of the contour of the ankle with obvious pitting. The incidence decreased as the voyage proceeded.

Newton (1944) described his alarm at finding oedema of his ankles on a voyage round Africa, and his relief at finding no albumen in his urine. He /

He noted that the oedema appeared after a week or more of profuse sweating in the Red Sea area, was always much improved by the night's rest, and disappeared as soon as a cooler climate was reached. Eichna, Bean et al. (1945) observed swelling of the hands in normal subjects under heat stress, and Allen and O'Brien (1944) described swelling of the limbs in cases of anhidrotic heat exhaustion.

Cases of heart disease are known to be more prone to develop ankle oedema in hot weather (Harrison,1939). Hall (1945) described pregnant women who developed ankle oedema in the hot weather which disappeared completely in the cold, in the absence of albuminuria or other signs of toxaemia.

Landis and Gibbon (1933) showed that the local increases in capillary pressure and filtration area associated with heat vaso-dilatation play their part in the production of heat oedema. Its incidence will be greater if there is excessive vaso-dilatation (Hardy et al.1941), in obese people whose heat loss must occur by vaso-dilatation rather than by conduction through tissues, and in those people who are unable to lose heat adequately by sweating. This probably accounts for the reports of oedema in some of the accounts of anhidrotic heat exhaustion,[1] and perhaps also contributes to the characteristic appearance of the skin in this syndrome when cases are exposed to heat. Eichna et al.(1945) noted swelling of the hands in normal subjects under heat stress in an artificial hot humid environment.

Brull (1946) stated that when normal people are obliged to remain immobile /

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[1] Chapter 11.

immobile for long periods they develop oedema. This may have accounted for the experience on a troopship of Munro (1944) who found a greater incidence in the troops than in the ship's company and staff, the latter probably being the more active group.

Henry and Gauer (1950) attributed the gravity-conditioned distribution of the oedema partly to their finding that the venous pressure in the ankles is greatly increased during vaso-dilatation. In adults, during vaso-dilatation produced by heat, even vigorous walking movements failed to reduce the mean venous pressure below 70 mm.Hg. The rate of fluid accumulation at pressures higher than this may well exceed the capacity of lymphatics to remove it. In the comfort zone far less activity was required to reduce the venous pressure below 70 mm.Hg., and, when cool, even normal involuntary postural movements will reduce it to 50 mm.Hg.

The syndrome is of relatively little importance as it disappears in most cases after acclimatization, and leaves no permanent disability.

Prickly heat.

The condition known as "prickly heat" has nearly as many alternative names as there have been remedies suggested for it. This observation emphasises the ignorance that still exists as to its aetiology in spite of the fact that it has been a continual source of annoyance and irritation ever since white men inhabited warm countries. While it has been the subject of many publications and controversies, no really thorough investigations with regard to its aetiology have been undertaken until within /

within the last few years. Perhaps because of its widespread occurrence it has suffered the same indifference as the common cold in temperate climates, and even the most illustrious figures in tropical medicine have paid it little attention. For example, Castellani, in a communication on "minor tropical disorders", which was criticized in discussion for "over elaboration", failed to mention prickly heat in fifteen pages devoted to diseases of the skin and hair (Castellani,1931), and he only gave it one sentence in his book, "Climate and Acclimatization" (Castellani,1938).

Prickly heat almost warrants classification as a "major" tropical disorder, judging by recent experience. It has been shown to be the precursor of anhidrotic heat exhaustion, a syndrome that affected one per cent. of the military population at risk in Karachi in 1946, and that was the commonest heat effects syndrome in Shaiba in 1943 (Ladell et al.1944) and in the American Desert (Wolkin et al.1944).[1] In addition to the severe discomfort and even distress prickly heat frequently causes, hospitalization is sometimes necessary, and anhidrotic heat exhaustion results in prolonged loss of man-power.

Prickly heat usually presents as a fine, superficial, papular eruption, sometimes surmounted by vesicles, with some erythema of the skin. The prominence of the eruption varies considerably and the erythema may be marked. It affects principally those parts of the skin which are normally covered, especially where there is friction, but the visible lesions are not always confined to these areas. It is aggravated as the subject is exposed to heat, and frequently becomes infected and eczematized /

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[1] Chapter 11.

eczematized, sometimes being associated with hydradenitis (small abscesses of sweat glands) and bullous impetigo.

There is an accompanying prickling, and sometimes itching, sensation in the skin, which may cause extreme discomfort. It usually appears as soon as there is a call to sweating, and becomes more aggravated as this continues. The distribution and severity of this symptom is not always directly related to the extent and severity of the skin eruption. Prickly heat is subject to inexplicable remissions and exacerbations.

Statements have frequently appeared indicating that prickly heat is associated with hyperhidrosis. While it may be true that excessive sweating may occur at the time that prickly heat appears, there is no doubt that even while the prickly heat is active in some areas, there may in fact be reduction in sweating elsewhere. Reduction in sweating is associated with its healing, and this may be mild and transient, or extensive and prolonged, in which latter case the syndrome of anhidrotic heat exhaustion may develop.

The numerous remedies that have at one time or another been claimed to relieve, and even to cure, it, have given little contribution to the understanding of its aetiology. One report (Radclyffe,1947) that relief from the intense itching was obtained from the use of "benadryl" does not appear so far to have been confirmed, but suggests that histamine at least contributes to the symptoms.

Studies of some of the environmental and individual factors in the aetiology of prickly heat have shown that the minimum air temperature and humidity /

humidity are important, there being an almost critical level for its occurrence.[1] It is more common and severe in hot humid climates than it is in the desert. It may be related to salt and water balance, as it has been shown that it can be relieved by increasing fluid intake and reducing salt intake, and can be made to relapse by increasing the intake of table-salt.[2] Dermatologists in America (including Sulzberger and Shelley) and O'Brien in Australia are conducting extensive experimental studies.[1,2] They have been concerned principally with noxious agents causing local prickly heat lesions, with special reference to the hypothesis that the proximate cause is a sweat duct obstruction to which many factors contribute.

No conclusion about the aetiology of prickly heat can be drawn until further investigations along these lines have been successfully completed, but its importance as a pathological effect of exposure to heat should not be underestimated.

Sunburn (erythema solare)

Sunburn, an acute erythema familiar even in temperate climates, may be an important effect of heat on the human body in the tropics, especially when large areas of skin are affected. It can lead to a breakdown of the thermoregulatory mechanism, firstly because the erythematous areas do not sweat, and may remain anhidrotic for up to several weeks (see plates 1-3, personal observations), and secondly because vasomotor control is temporarily /

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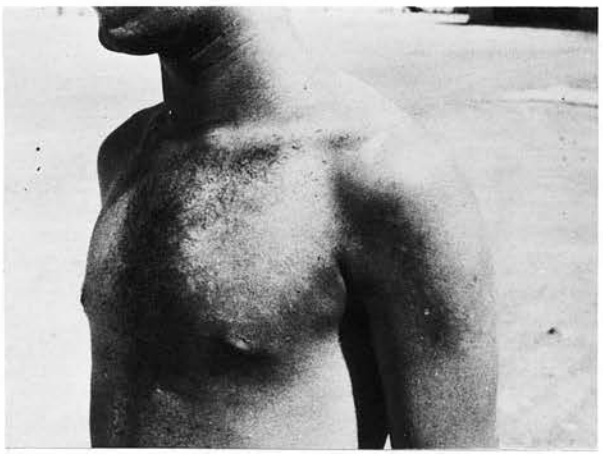
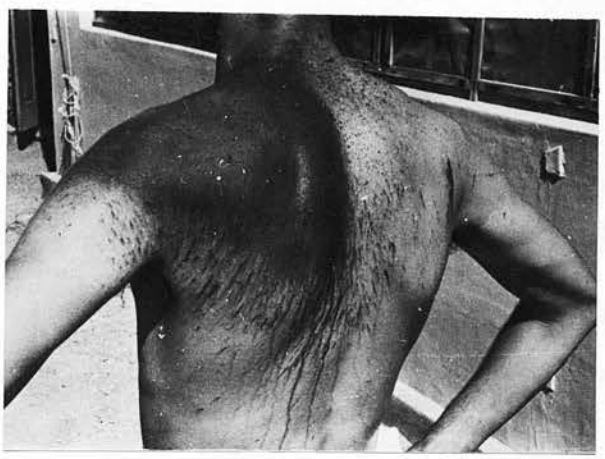
[1] Chapter 16.
[2] Chapter 15.

temporarily lost over these areas. Extensive sunburn may lead to considerable temporary upset including fever, headaches, and occasionally vomiting, which may be associated with excessive histamine release.





PLATES 1,2,3. Effect of severe sunburn on sweating.

Plates 1 and 2 show the almost complete absence of sweating (demonstrated by the gentian violet powder technique described in chapter 11) over the shoulder region affected by severe sunburn. Plate 3 shows normal sweating in the same subject six weeks later.

CHAPTER 8.

THE SIGNIFICANCE OF HYPERVENTILATION AND URINARY SYMPTOMS IN HEAT EFFECTS SYNDROMES.

Hyperventilation.

Hyperventilation occurs commonly in men exposed to heat, and was the subject of careful study by Bazett (1927), who observed that the severity of hyperpnoea was directly related to the rate of rise in body temperature and to its absolute temperature. While it may be partly associated with a call for a higher rate of oxygenation of the blood and for increased heat dissipation, its importance appears to be mainly associated with the acid-base mechanism. The symptoms produced by hyperpnoea itself are of considerable importance in the clinical picture presented by heat effects syndromes.

Faintness, tingling of the extremities and mental confusion were noted in the hot bath experiments of Bazett and Haldane (1921), but they also occur in voluntary hyperpnoea in the absence of heat. The recent analysis of the clinical symptomatology of hyperventilation by Engel et al.(1947) shows the possible contribution made by this phenomenon in heat effects syndromes. They pointed out that even the act of voluntary hyperventilation is fatiguing in itself, and that the principal symptoms it causes include /

include numbness and tingling of the hands, feet and face; buzzing in the head; varying degrees of reduction in the level of consciousness, described as dizziness, light-headedness, giddiness and faintness; blurring of vision; dryness of the mouth; stiffness of the muscles, and tetany. The longer it occurs the more likely is tetany to occur, but McCance (1932), Schultzer and Lebel (1939) and others have shown that there is very great individual variation in the occurrence of tetany during over-breathing. Engel et al. (1947) found that, in general, the more marked the reduction in consciousness, the less were the numbness and tingling and the less likely was tetany to appear; the younger the subjects the more likely were they to develop disturbance of consciousness during hyperventilation; and with lower blood sugars there was greater reduction in consciousness, higher blood sugar allowing the subjects to ventilate for longer periods and so allow tetany to develop.

They showed that reduction in consciousness during hyperventilation ran parallel with slowing of frequency of the electroencephalogram, and that, although in the erect position there was a more rapid pulse rate, the slowing of frequency was not correlated with a fall in blood pressure. None of their experimental subjects actually fell while unconscious, and they concluded that true syncope ("vasodepressor syncope") occurs relatively infrequently in hyperventilation. When anxiety was a prominent symptom, syncope could occur - the electroencephalogram showed changes of hyperventilation, and the circulation showed the change of vasodepressor syncope. In those subjects with postural maladaptation (where the blood pressure /

pressure tended to fall in the erect position) hyperventilation tended to accelerate the process. When the hyperventilation was hysterical in origin "hysterical syncope" or "hysterical convulsions" might occur, during which the electroencephalogram showed no significant slowing and the circulation showed no characteristic changes. Psychiatric examination of these sybjects always revealed the "characteristic dynamics" of hysteria, and the syndrome could be easily reproduced experimentally.

In the light of these observations it is obvious that the hyperventilation that occurs in some types of heat effects will considerably influence the clinical features. The observation of Boutwell et al.(1950) that a"rebound acidosis" follows the period of acapnic alkalosis after hyperventilation may also have a bearing on symptomatology.

Hyperventilation occurs most commonly when there is impaired sweating (heat stroke and anhidrotic heat exhaustion) and so may be related at least partly to the failure of adequate elimination of lactic acid by the sweat glands.

Ladell et al.(1944) noted the occurrence of dyspnoea in 23 out of 55 cases of anhidrotic heat exhaustion, and in 8 it was associated with tingling and numbness of the extremities. One of the cases of Wolkin et al. (1944) complained of "pins and needles" all over the body. Sulzberger et al. (1946) found that their patient "hyperventilated sufficiently to blow off 25 per cent. of his circulatory CO_2 during 80 minutes in a hot environment", but no symptoms or signs of tetany developed.

O'Brien (1948) was loth to accept that the hyperpnoea of anhidrotic heat /

heat exhaustion disturbs the acid-base balance on the argument that "whereas tetany is prone to develop in normal man during over-breathing not once has it been seen as a complication of" anhidrotic heat exhaustion, although he acknowledged that the numbness and tingling in the limbs complained of by the patients of Ladell et al. (1944) indicated possible latent tetany. As has been demonstrated, it is likely that such patients collapse before tetany develops.

At Karachi in 1946 dyspnoea was complained of by 41 per cent. of the cases of anhidrotic heat exhaustion and collapse,[1] but no observation was made on the occurrence of tingling and numbness. Hyperpnoea appeared to be a prominent feature of the stage of collapse in this syndrome, and was probably an important factor contributing to the collapse. This would account for the observation that subjects with anhidrosis could be brought to the verge of collapse more easily than normal subjects during hard physical exercise in a hot room.[1]

The hysterical element may also play a part, and would help to explain why, although the majority of cases of anhidrotic heat exhaustion at Karachi developed hyperpnoea only on exertion, some had the symptoms under circumstances when heat strain did not appear to be increased. Hyperpnoea and tingling of the skin have been described in cases of heat hyperpyrexia and heat stroke, and it is likely that the clouding of consciousness may be contributed to by the hyperventilation.

The hyperpnoea that may accompany hard work in the heat, even in the presence of adequate sweating and heat loss, probably contributes to the symptomatology /

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[1] Chapter 11.

symptomatology of circulatory heat exhaustion and collapse. In this respect it is of interest to note the incidence of tetanic symptoms in cases of this type described in the quotation by Wallace (1943) in chapter 7, where there is no reason to believe that the subjects had acquired anhidrosis. In six of these cases there was carpo-pedal spasm, and they were found to have a CO_2 combining power of the blood which varied between 70 and 112.

The incidence of hysterical hyperventilation leading to tetany in cases of severe salt depletion is discussed in chapter 7. The explanation may be that the impaired cerebral circulation present lowers the threshold for hysterical symptoms, or the lowered plasma chloride may predispose to tetany.

Polyuria and frequency of micturition.

Marked polyuria, frequency, and urgency of micturition are described as occurring commonly in heat hyperpyrexia and heat stroke, and in anhidrotic heat exhaustion and collapse. For example, Couldrey (1919) describing his own symptoms during a period of heat hyperpyrexia, stated that he passed urine frequently, at least a pint at a time, with a specific gravity of 1001 to 1005. Moss (1927) stated that in miners a copious secretion of urine usually coincided with dryness of the skin, and many observers have commented on the pale urine of such polyuria. Sunderman (1941) reported a diuresis in patients with the anhidrotic type of congenital ectodermal defect when they were exposed to heat, and Thurnham (1848), describing the first case of this type in the British literature, stated that /

that the "urinary secretion was very abundant and usually clear".

Analysis of clinical reports suggests that polyuria occurs coincidentally with hyperventilation. At Karachi in 1947, polyuria was demonstrated at the end of an experimental period of severe heat strain in two subjects, one with acquired generalised anhidrosis, and one with severe and extensive sunburn of the thorax and trunk (personal observation).

The polyuria that accompanies hyperpnoea when subjects are experimentally immersed in a hot bath (other than the characteristic diuresis of the first hour noted by Landis et al.,1926) has been attributed by some observers (Bazett et al.1924, Griffiths and Hansell,1925) to hydrostatic pressure exerted on the abdomen by the water in the bath, but a diuresis has been observed in voluntary hyperpnoea in an ordinary environment (Collip and Backus,1920). The diuresis is assumed to be related to alkalosis resulting from hyperpnoea. Diuresis is recognized as a feature of alkalosis (Peters and Van Slyke,1946), and Sanderson (1948) has observed it to occur in alkalosis even in the presence of severe dehydration.

Even in normal environments a rapid increase in the filling rate of the bladder results in undue frequency of micturition, and it is possible that under tropical conditions, where the bladder is unaccustomed to dealing with large quantities of urine, frequency may be greatly increased. In addition, a greatly altered pH of the urine may act as a further irritant and help to account for the extreme urgency sometimes encountered ("I cannot hold my water" was the almost invariable complaint of soldiers in India just before the onset of heat stroke, according to Maclean,1868).

Polyuria /

Polyuria might, of course, be aggravated if a large quantity of water were drunk, but it occurs independently of this. It is unlikely to be due directly to the transfer of fluid mobilized for sweating from the surface of the body to the kidneys as a result of cessation of sweating.

While there is some evidence that in anhidrotic heat exhaustion polyuria may persist for several days after admission (Ladell et al.1944, Allen, personal communication to O'Brien,1948), the interpretation of this observation is difficult because of varying fluid intakes and the absence of information about the environment of the patients and their other symptoms during this period. However, O'Brien (1948) recorded the diurnal variation in the reaction of the urine of a patient with anhidrotic heat exhaustion resting in hospital over a period of six days, and commented on the large number of pH readings at or above 7.5 during the heat of the day, and accepted this as evidence of alkalosis.

From the evidence available it would appear therefore that the polyuria and resultant frequency are secondary to the change in acid-base balance induced by hyperventilation.

CHAPTER 9.

CORRELATION BETWEEN HEAT EFFECTS SYNDROMES AND CLIMATE AND ENVIRONMENT.

Shattuck and Hilferty (1936) made an attempt to analyse the distribution of acute heat effects in various parts of the world, but found the data available very inadequate for the purpose, commenting on incomplete reporting, differing classifications of the effects of heat, and incorrect figures for populations. They noticed outstanding fluctuations in heat effects in certain countries in certain years and concluded that at least some of the irregularities of distribution could be explained as due to climatic factors peculiar to restricted localities. They indicated the necessity for studying climatic variations from day to day, and the occupation and mode of life of the victims.

Rogers (1908), Willcox (1920), Hearne (1932), Morton (1932), Wallace (1943), Ladell et al.(1944), Shepherd (1945), and Borden et al.(1945), attempted to correlate heat effects syndromes with climatic conditions, and Moss (1927), Weiner (1938) and Caplan (1943), with hot environments underground. They showed that in general the incidence of heat effects was related to "waves of excessive atmospheric heat", that the wet bulb temperature and air movement were very important factors, and that living and working conditions were also important. There is an obvious correla-

tion /

correlation of heat effects with heat waves in temperate climates.

The comparative incidence of heat effects occurring during the construction of the Boulder and Hoover dams between 1931 and 1934 is unfortunately vitiated by the varying living conditions and precautions adopted during the period concerned, but there is no doubt that the large number of cases of heat stroke occurring in 1931 was attributable to the exceptionally high dry bulb temperatures occurring that year (Zwalenburg,1935, McDaniel,1935).

There appear to have been only two detailed surveys of all cases of heat effects in any one place in one hot season. These were made at Shaiba, Iraq, by Ladell et al.(1944) and in Florida by Borden et al.(1945), and the second of these two reports is difficult to interpret because of the inadequate clinical classification adopted. As the relative incidence of the different syndromes in different types of climate should provide essential information for determining the particular environmental factors concerned in the production of these syndromes, the distribution at Karachi (based on personal observations) has been compared with that at Shaiba.

Personal observations at Karachi.

At Karachi, detailed climatic data served to clarify the nature of the syndrome of anhidrotic heat exhaustion, and further information was obtained by comparing the syndrome as it occurred in Shaiba where the climate was in some respects very different.[1] The same data can be used to /

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[1] Chapter 11.

to show the relative incidence of the various types of heat effects syndromes in different types of climate.

The source of the data and their accuracy are discussed in chapter 10. The differences in the climate between two of the summers is described in detail in chapter 11. Briefly, although 1946 was very much more uncomfortable than 1947, the only measurable difference was that the minimum dry bulb temperature and wet bulb temperature were a few degrees higher in 1946. Even in the hottest part of the summers the maximum dry bulb temperature was never above 95 deg.F. except for a few isolated days in 1947. There was a high humidity, however. Meteorologically, 1945 was similar to 1947, except that there were fewer days with a high dry bulb temperature. At Shaiba, in 1943, the dry bulb temperature during the summer ranged between 110 deg. and 120 deg.F., but the humidity was low. Karachi, therefore, in spite of being on the edge of the Sind desert, had a "jungle" type of climate, Shaiba, a "desert" type.

Table II summarizes all the cases of heat effects at Karachi in 1945, 1946 and 1947, and at Shaiba in 1943 (hospital admissions) (Ladell et al. 1944). There was only one case of heat stroke in all the three years at Karachi, and no cases of heat hyperpyrexia. At Shaiba there were 12 of each. In 1946 at Karachi there were a few cases of hyperpyrexia secondary to such illnesses as chickenpox as well as malaria.

At Karachi there were no cases of chloride deficiency due solely to environmental heat. In 1946 four patients were ill enough to require intravenous saline, but in each case the hypochloraemia was secondary to diarrhoea /

TABLE II.

Incidence of heat effects syndromes in desert and humid climates.

Type of climate	DESERT	HUMID		
Place	Shaiba, Iraq	Karachi, India		
Source of data	Ladell et al. (1944)	Personal observations+		
Year	1943	1945	1946	1947
Number of men at risk (approximate)	not stated	at least 6,000	6,000	5,000
Heat stroke	ø 12	0	1	0
Heat hyperpyrexia (primary)	⧗ 12	unknown	⋇0	0
Heat hyperpyrexia (secondary to febrile illnesses)	some but no. not stated	unknown	a few	0
Chloride deficiency (due to effects of heat)	45	0	0	0
Anhidrotic heat exhaustion and collapse	55 (varieties			
(a) with complete anhidrosis	not distinguished, but	few, if any	⋇58	2
(b) with incomplete anhidrosis	majority probably incomplete)		0	2
Heat syncope and circulatory heat exhaustion and collapse	not stated	unknown	20–30	a few
Prickly heat	fairly common	very common but not severe	very common and severe	very common but not severe

\+ 1945, compiled from hospital records, and so less complete and less reliable than the other two years.

ø Described as "hyperpyrexia", but clinically all were cases of heat stroke.

⧗ Described as "borderline hyperpyrexia", with an average rectal temperature of 104.8 deg.F. They resembled "hyperpyrexia" cases except in the actual height of the temperature and absence of mental confusion. The criterion for hyperpyrexia was a rectal temperature of 107 deg.F.

⋇ One case of anhidrotic heat exhaustion had an oral temperature of 106 deg.F.

diarrhoea. In 1947 no indigenous cases were seen, but men were taken ill with hypochloraemia on train journeys through the hinterland, which had the typical dry and very hot climate of the desert. There were 45 cases of chloride deficiency at Shaiba.

In 1946 there was an abrupt outbreak of anhidrotic heat exhaustion at Karachi. Fiftyeight cases occurred, nearly all of them in the last fortnight of June. In 1947 there were only 4 cases, although approximately the same number of men were at risk. In 1945, the syndrome had not yet been recognized and a few cases may have occurred. A review of the hospital records, however, revealed only one undoubted missed case, and he came from outside the Karachi district. All of the cases in 1946 were completely anhidrotic, two of the four in 1947 were not. At Shaiba the majority of the 55 cases were probably not completely anhidrotic. The significance of this observation is discussed in chapter 11.

Little information is available about the incidence of heat syncope and circulatory heat exhaustion and collapse, as this type of case rarely reached hospital. At Karachi it is known that there were 20 to 30 such cases in 1946, and a few only in 1947.

At Karachi prickly heat was always common and moderately severe, but its incidence and severity were greatest in 1946. At Shaiba it was common, and probably fairly severe towards the end of the summer.

Other /

Other observations.

Other published accounts show the same distribution of heat effects. Reports from hot dry areas emphasise the importance of heat stroke and dehydration heat exhaustion and collapse; reports from humid areas do not, and Hearne (1932) stated that heat stroke never occurs in the humid climate of Colombo, where the highest dry bulb temperature ever recorded up to 1932 was 98.5 deg.F. Caplan (1948) stated that heat stroke has not been seen in miners working at the Kolar Gold Field, where there was a dry bulb temperature of 105 to 115 deg.F. and a wet bulb temperature of 80 to 90 deg.F. On the other hand, the majority of the accounts of anhidrotic heat exhaustion and collapse came from humid areas, where prickly heat is also more common and more severe.

The syndrome of exercise precipitated circulatory heat exhaustion and collapse occurs in both types of environment, and has been reported principally in groups of men doing hard physical work, such as soldiers in training and underground miners. In really hot environments it is usually associated with some degree of chloride deficiency.

Tropical neurasthenia appears to occur more commonly in hot humid climates which are usually of a monotonous character, such as West Africa, Malaya and Bengal.

Conclusions /

Conclusions.

These observations confirm generally the conclusions drawn in chapter 6 on the expected distribution of the clinical syndromes caused by exposure to different types of environmental heat and based on physiological principles, and help to justify the classification of these syndromes proposed in chapter 7. With this knowledge it should be possible to anticipate the particular hazards of any known environment, and so help to reduce morbidity, and to avoid mortality.

PART II.

CHAPTER 10.

INTRODUCTION

Many of the original observations and investigations on the effects of environmental heat described in the subsequent chapters were conducted in the Far East from 1943 to 1947, and in particular at Karachi, India (now Pakistan) in 1946 and 1947. Some observations were also made elsewhere in India and Burma and in Singapore, and at sea in the tropics. Up till 1946 the author was a medical specialist in the Royal Air Force (latterly officer in charge of the medical division of the R.A.F. Hospital at Karachi), and had full charge of the patients under investigation. During most of this time he was also acting as consultant dermatologist. In 1947 he continued the investigations as a civilian, but was granted all the facilities previously available, and had access to additional scientific apparatus.

At Karachi in 1946 and 1947 there was a unique opportunity of studying the effects of environmental heat. There was a relatively stable Service population under more or less peace-time conditions, and facilities for detailed observation and investigation of cases were good. The R.A.F. Hospital was the only hospital in the area for the reception of cases, and for specialist opinion. There was good liaison with the medical officers of local units, and general observations and special investigations /

investigations were extended to men on some of these units. It is believed that in both years all cases of the major syndromes due to environmental heat were observed personally, and accurate data was also available about the minor syndromes that did not reach hospital. During 1946 all the dermatological cases in the hospital were under the care of the author, and he was also granted access to the cases in 1947. Medical records of previous years were available for consultation.

The contrasting climatic conditions at Karachi were of great assistance, as the summer of 1946 was the hottest in living memory, and that of 1947 was average. Detailed meteorological data were available from civilian and Service sources at three separation stations in the area. Both in 1946 and 1947 several cases of heat effects syndromes were flown home to this country under the escort of the author, and investigations continued here. Some of these were conducted in a specially designed room at the Accident Hospital at Birmingham (by kind permission of Dr. L. Colebrook,F.R.S.), where tropical conditions could be simulated. Other investigations were conducted on men recently returned from the tropics, and on other normal subjects, at Edinburgh, and at the Royal Scots Depot Glencorse, Midlothian.

As a result of this work it has been possible to define a new heat effects syndrome, anhidrotic heat exhaustion, (based on experience of 66 cases) and to make several important physiological, biochemical and histological observations on the cases; to clarify the physiological and meteorological factors bearing on this and other major heat effects heat syndromes; /

syndromes; to show the influence of detailed climatic conditions on different types of skin diseases; and to show the influence of individual, environmental, and metabolic factors in the aetiology of prickly heat.

Some of these observations have already been referred to in the following original publications:

"Anhidrotic heat exhaustion." Trans. R.Soc.trop.Med.Hyg. (1950) 44, 193. (with Dr. R.H. Mole).

"Mammillaria." ibid. (1951) 44, 465. (with Dr. R.H. Mole).

"Comparative physiological observations on prickly heat, mammillaria, and anhidrotic heat exhaustion." ibid. (to be published) (with Dr. R.H.Mole).

"The effect of water and salt intake on prickly heat." Lancet. (1949) 2, 279. (with Dr. R.H.Mole).

"Environmental and individual factors in the aetiology of prickly heat." J. Invest. Derm. (to be published)

"Climatic environmental factors in the aetiology of skin diseases." ibid. (to be published).

All the material in the subsequent chapters is based on personal observations and investigations, except where otherwise stated. Experimental details, scientific methods, and the original data from which the tables, diagrams and graphs have been constructed and other conclusions made, are contained in the Appendix.

CHAPTER 11.

ANHIDROTIC HEAT EXHAUSTION AND COLLAPSE.

Heat effects syndromes of a very similar type have recently been described independently in Northern Australia (10 cases) and New Guinea (12 cases) by Allen and O'Brien (1944), and called by them "tropical anidrotic asthenia"; in the American desert (8 cases) by Wolkin et al. (1944), and called by them "thermogenic anhidrosis"; and in Shaiba, Iraq (55 cases) by Ladell et al. (1944), and called by them "heat exhaustion type II". The differences among these accounts have been critically reviewed by Waterlow (1945), Lancet (1946) and O'Brien (1948). The additional evidence to be presented here shows that all these authors were in fact describing the same syndrome, each emphasising different aspects of it, depending partly on the circumstances in which the cases were seen.

One similar case has been described in Louisiana (Blank, 1944), seven cases in the South Pacific (Novy and Ramsey, 1944, Sulzberger et al. 1946, Fox, 1949), and fourteen cases in Cawnpore, India (Parkinson, personal communication, 1946). Sixty-two cases from the Karachi area of India (now Pakistan) and four from Cawnpore are described in this chapter. Further cases are known to have occurred in other parts of India and in Singapore (Bowe, Calnan and Friend, personal communications, 1946).

The syndrome is therefore widespread but it is only during the last few /

few years that it has been recognised. The principal features are physical and mental exhaustion, aggravated by exposure to heat and physical exertion, and sometimes so severe as to cause collapse; polyuria and frequency of micturition; reduction or cessation of sweating except notably on the face; and a dry and unusual skin. There is nearly always a preceding history of prickly heat; hyperpyrexia is rare; the return of sweating is slow. The syndrome is not related to chloride deficiency.

The name "anhidrotic heat exhaustion" (or collapse) has been chosen for the syndrome in preference to those previously used: "anhidrotic"[1] because failure of sweating is the essential lesion of the syndrome; "heat" rather than tropical, because heat strain, which is the cause of the syndrome, depends on exertion as well as on environment, and because the majority of the cases have been reported from outside the true tropics; and "exhaustion" because this is the best single word to describe the symptoms. Sometimes actual collapse is present, when the name "anhidrotic heat collapse" has been used.

It is surprising that no reference was made to the syndrome in recent analyses of large numbers of heat effects by Maclean (1943), Morton (1944), Borden et al.(1945), Park (1945), and Shepherd (1945), or in the older accounts, such as that of Willcox (1920). Allen and O'Brien (1944) stated that /

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[1] "Anhidrotic" strictly implies a complete absence of all sweating. This probably never occurs in acquired anhidrosis and the term is used throughout to imply a reduction in sweating (usually with complete absence of sweating on the trunk). As will be shown later the degree of sweating deficiency necessary to produce symptoms may be large or small according to circumstances.

that the significance of the first case in their series was not appreciated until further cases were found that did not conform to the usual classification of heat effects. Wolkin et al.(1944) admitted that they would have probably recognised a larger number of cases of the syndrome had they been aware of its nature earlier. A review of the case records for 1945 at the Hospital in Karachi revealed at least one unrecognised example of the syndrome, and other unrecognised cases are referred to in this chapter. These examples illustrate the way in which ignorance of the existence of the syndrome may have led to its being overlooked.

At Karachi other types of heat effects with which the syndrome could be confused were uncommon, and in 1946 cases of the syndrome were numerous and easy to recognise. A detailed analysis of symptomatology and of various aetiological factors was made and on this foundation it was possible to attempt a definitive description of the syndrome, and to show that the clinical picture could vary considerably with the circumstances in which the cases were seen.

One of the major points of interest in the syndrome is its relationship to heat stroke. In both the skin is dry and anhidrotic, but in other respects the typical clinical pictures differ. Further observations are still needed to discover if the syndromes are really unrelated or if there is a continuous gradation from one to the other.

CLINICAL MATERIAL, 1946.

During the summer of 1946 at Karachi, India, 58 British personnel of the Army and Royal Air Force with the syndrome of anhidrotic heat exhaustion or collapse were studied, 50 in hospital and 8 in unit sick quarters. Complete particulars are not available for every case in the smaller group and in the analyses percentage and absolute figures are given. Fifty-five of the cases were men who had served continuously in the Karachi area for at least four months before the onset of the syndrome. Of the remainder, one had been there for two weeks and two for one day only, when they were admitted, but they had spent the earlier part of the summer in other hot areas of India. The dates of onset of the first symptoms and of admission to hospital or sick quarters are shown in figure 6 (page 169).

The following are illustrative histories, grouped according to the way in which the cases presented.

I. With symptoms, but not collapsed.

Case 1. This soldier stated that prickly heat had begun two months before the onset of the syndrome, and had gradually become more severe and extensive. Profuse sweating had been the subject of comments by his friends. About two weeks before admission to hospital he became aware of a reduction in sweating and the prickly heat began to improve, although he had taken no action to reduce sweating and had used no local application on the skin.

Twelve days before admission he noticed that sweating on the body had ceased, although it persisted on the forehead, face and upper lip. From that time he began to feel more easily tired and to lose interest in his work. He felt drowsy and unable to concentrate, and occasionally complained of slight headache and dizziness. These symptoms tended to become worse during the day and persisted till about 7.30 in the evening when they would become less marked. He always felt worse when walking about, and especially if exposed to /

to the heat of the sun. On one occasion the development of exhaustion symptoms by the middle of the morning made him cancel a dance engagement for that evening but by evening he had improved so much that he felt the cancellation had been unnecessary.

He tried the effect of taking extra salt and water but this did not relieve his symptoms. On one occasion he played a game of hockey in the evening in an attempt to restore sweating, but had to leave the field at half-time on account of feeling very hot and short of breath. He never actually collapsed or fainted.

Frequency of micturition and polyuria had been present for several days. He had to micturate every three-quarters of an hour during the day, but not during the hours of sleep. His urine was abundant and pale in colour. He felt thirsty and drank a great deal of water. Appetite was not affected until about three days before admission when he began to complain of slight nausea, but vomiting did not occur. He had not complained of any muscle cramps. Examination confirmed complete absence of sweating on the body and the profuse sweating on the face.

Case 2. This soldier was admitted to hospital because of gastro-enteritis and after it had cleared up he was transferred to the skin wards on account of severe prickly heat which had failed to improve during his stay in bed. On the first occasion on which he was sent to the dining hall for his midday meal, a walk of 150 yards in each direction in the noonday heat, he complained, on his return, of feeling hot, weak and dizzy, and of a slight headache. His oral temperature was found to be 100 deg. F. A careful history taken four hours later revealed that he had not been sweating all day, and that he had had marked frequency and polyuria since the early morning. Examination showed absence of sweating on the whole of the body except the face.

Case 3. This soldier felt perfectly well when he set out on a route march, but before going very far he began to feel "queer". He was able to carry on for a short time but gradually felt more and more exhausted and short of breath. At the first stop he complained of feeling very sick and drank a good deal of the contents of his water bottle. He was able to start with the others again, but soon had to drop behind. His friends remarked that he was perfectly dry except under the armpits, while the tunics of the others were /

were black with sweat. He felt very thirsty and finished his water bottle, hoping that drinking would restart his sweating. Shortly afterwards he began to pass urine for the first time since the beginning of the march, and then continued to do so every five minutes. He was eventually able to get a lift back to his Unit, drinking copiously all the time. He reported sick, was told that his oral temperature was 104 deg.F. and his pulse rate 120 per minute, and was immediately sent to hospital. He was never really unconscious, but was very near to it.

Two days previously he had had a similar experience while playing football - he had felt very weak and wanted to vomit, but had been able to finish the game by taking things easily. After a cold shower he felt better; he could not eat anything, but drank copiously, and was aware that he was not sweating.

On examination after admission to hospital there was absence of sweating on the body and profuse sweating on the face.

II. In collapse.

Before admission these cases were treated by Unit medical officers, usually by artificial cooling and saline by mouth. A rapid improvement always occurred, but a few cases relapsed into a semi-collapsed state by the time they reached hospital.

Case 4. This airman was playing cricket in the early evening, and during an innings that included many single runs he began to feel weak and giddy. He had to sit down at the wicket and then retire. He was taken to the Unit sick quarters where the medical officer described him as being semi-comatose. His oral temperature was 104 deg.F. and his skin was noted to be dry. He was cooled down by means of iced water and a fan, and given large quantities of saline to drink, and rapidly recovered. His oral temperature was 100 deg.F. when he left sick quarters, and 99.6 deg.F. on admission to hospital.

Enquiry revealed that prickly heat had begun about six weeks previously and had spread to involve the trunk and arms. Although climatic conditions had not improved, the prickly heat had begun to clear up spontaneously, at the same time as sweating diminished, and had eventually disappeared completely. There had been no exhaustion symptoms prior to the game of cricket, and no frequency of micturition or polyuria had been noted.

Case 5 /

Case 5. This soldier noticed about the middle of June that he was unusually tired and also that sweating on arms and legs had stopped. As a batman he was able to take things easily and after a few days his tired feeling passed off and sweating returned to normal.

A week later he did a practice parachute drop. After rolling his parachute and carrying the heavy package across the sand, he noticed he was not sweating except on the forehead, in spite of the intense heat. He sat down in the shade of a truck, his breath coming in gasps and his heart beating very strongly. After this rest he had to join the others in a search for a lost parachute, but after half a mile he found he could not go on and had to lie down. On return to camp he intended to report sick after putting his kit away, but just as he got into the barrack room he "passed out". On recovering consciousness he found himself being cooled down by wet applications. On arrival at hospital his pulse rate was 74, oral temperature 100 deg.F., and rectal temperature 101 deg.F. Sweating was present on the forehead only.

There was no history of frequency or polyuria but thirst had been marked all day. Prickly heat had begun three weeks before the first anhidrotic episode.

III. Without overt symptoms.

These cases reported sick on account of skin disease, but examination at hospital prompted further enquiry which revealed that all of them presented the syndrome.

Case 6. This airman was sent to hospital with severe and extensive bullous impetigo, but when it was found on examination that sweating was absent a careful history was taken. He had had extensive prickly heat for about a month, but the rash had cleared up a week before his reporting sick and the prickling sensation two days later. In its place had appeared the present rash. He had been doing fairly heavy indoor and outdoor work, and admitted that he had felt more easily exhausted during the last week, and had had occasional headaches and some degree of anorexia. Polyuria and frequency had been marked for several days. Sweating had been reduced for several days before the prickly heat had cleared up, and he had taken extra salt in an attempt to restore sweating. He had not sweated anywhere except on the forehead and in the axillae on the day of admission.

Symptomatology.

The case histories, of which samples have been given, were very similar, and a composite history has been constructed from them. The patients presented a group of symptoms that were classifiable under the heading of "exhaustion" or "physical and mental asthenia"; an increased tendency to physical tiredness; lack of interest in work and difficulty in concentration, sometimes to the extent of feeling drowsy; a feeling of uncomfortable warmth; shakiness and dizziness; slight headache; slight anorexia; tendency to be irritable. These exhaustion symptoms were present in varying intensity and proportions in different patients, depending no doubt to some extent on the individual's threshold for such symptoms, but principally on the heat stress to which he was exposed.

During physical exertion, especially in the middle of the day, there could be such a marked exacerbation of symptoms that the patient could be described as having an "attack". Symptoms then included an intense feeling of warmth, hyperpnoea, palpitations and sometimes nausea, polyuria and frequency of micturition, acute distress and even collapse with clouding of consciousness, as described in case-histories 3, 4 and 5. The severity of the symptoms was not always proportional to the degree of heat stress imposed by exertion and exposure to the sun, and a few patients complained of quite marked distress even while performing sedentary duties.

The patients recovered fairly quickly from the collapse when they were removed from the heat, especially if they were cooled artificially, but /

but the more chronic exhaustion symptoms sometimes persisted. The patients had usually recovered from the collapsed state by the time they were seen in hospital.

In 46 per cent. (23) of the cases an acute exacerbation of symptoms resulted in admission to hospital, either during or shortly after the "attack", as in cases 4 and 5, although by the time the case reached hospital the majority of the symptoms had passed off. In a few of these cases, however, the body temperature was found to have risen again during confinement in the ambulance during transfer to hospital.

In 46 per cent. (23) of the cases the men were able to carry on their duties for several days in spite of symptoms, but eventually reported sick in the ordinary way in the morning (case 1). In half there was a history of earlier attacks not severe enough to lead to hospitalisation.

In 8 per cent. (4) of the cases the syndrome was discovered only when suspicion was aroused during examination of patients presenting with skin disease. Symptoms of the syndrome had been present but had not been prominent enough for these particular individuals to complain (case 6).

During attacks breathlessness was a prominent symptom, and was complained of by 16 cases; it was complained of even at rest by 2 (total, 39 per cent.). Nausea was also prominent during attacks, and sometimes vomiting occurred. Only one patient complained of abdominal pains associated with vomiting and he was chloride deficient as well.

Disturbances of micturition were common, but in some cases it was not easy to distinguish between frequency and polyuria. 32 (64 per cent.) complained /

complained of frequency and polyuria and 3 (8 per cent.) of frequency only. The frequency was sometimes very marked (every few minutes in case 3), but was rarely nocturnal. Several patients stated that they required to micturate almost immediately after each drink of water.

Insomnia was never a spontaneous complaint and was found on interrogation to be an unreliable symptom in the majority of cases. None of the reliable witnesses stressed any increase in the tendency to insomnia common among all personnel under the prevailing climatic conditions.

Every patient gave a history of having had some degree of prickly heat for a variable time before the onset of symptoms, and all of them except one (a very poor witness) had been aware of, or could recall in retrospect, the clearing up of the prickly heat. All realised that there had been a reduction in the amount of sweating "all over the body" - for instance a patient would find that he could brush the dry sand off his skin after sprawling on the ground during an exercise, or that his tunic was obviously dry when all the others' were black with sweat (case 3).

Where the reduction in sweating had been gradual and there was no precipitating factor, such as physical exertion, to draw attention to it, the elicitation of the history was sometimes more difficult. On questioning, however, many admitted that sweating had persisted on the face and was often profuse, especially the forehead, even when sweating on the trunk and limbs had ceased. A few patients volunteered that they had been sweating excessively for a period before the reduction occurred, but the evidence was not sufficiently reliable in most cases to make this point /

point worthy of analysis, especially as profuse sweating was almost universal at the time, and individual variations in the degree of sweating were to be expected.

Most of the patients had also been aware of a change in the skin when the prickly heat cleared up, and a characteristic gesture often accompanied their explanation, indicating the widespread and uniform nature of the new appearance and sensation of the skin in contrast to the usually patchy distribution of the prickly heat.

Examination.

Except during or soon after an attack the general condition of the patients did not call for special comment. There were no clinical signs of dehydration and they did not appear ill. During an attack, however, there might be mild anxiety, acute distress, or even collapse with clouding of consciousness, depending on the stress to which they had been exposed. Flushing and profuse sweating of the face, hyperpnoea and tachycardia were then prominent.

Body temperature.

Some degree of pyrexia was usually present. In 13 the highest oral temperature recorded was less than 100 deg.F., in 24 it was between 100 and 102 deg.F., in 12 it was between 102 and 104 and in one case it was 106 deg.F. Physical exertion in the sun, such as a route march, had been the precipitating factor in 8 of the 13 cases with a temperature over /

over 102 deg.F., and in two of the remainder there was coincidental disease (spondylitis and severe pyogenic infection of the skin).

Sweating and the skin.

Detailed information about the state of the skin and the degree of sweating at the time of examination by unit medical officers was incomplete. At the first examination in hospital the two most striking features in every case were (1) the characteristic appearance of the skin, to which the name "mammillaria" has been given, and which is described in detail in chapter 12, and (2) the uniform absence of sweating on the body from the neck downwards, including the limbs. The skin felt hot and dry, but not so intensely hot as, for instance, in the pyrexial stage of malaria, and was pale in contrast to the red flush of the face.

Sweating of the palms of the hands, soles of the feet, and, most obviously, the face, (plate 4) was often noted although there was complete absence of sweating elsewhere. If moisture was present at all on the trunk it was found in the region of the waist, especially around the umbilicus. In several cases examined after they had been lying in bed for a few hours, the skin of the underside of the trunk was found to be slightly damp. This was probably due to the incomplete evaporation of insensible (non-glandular) perspiration.

Anhidrosis of the body was demonstrated in cases of the syndrome at rest and after stimulation by heat and physical exercise by dusting the skin with talc containing 5 per cent. gentian violet, which becomes dark purple when wetted. Initial tests were carried out in the still atmosphere /

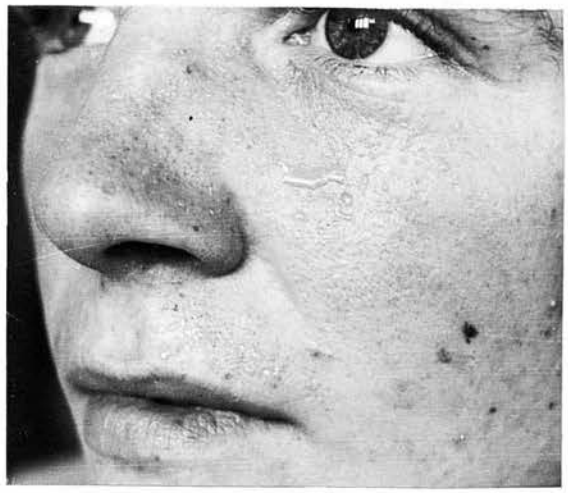


PLATE 4. Excessive sweating on the face in a subject with anhidrotic heat exhaustion in contrast to the complete dryness of the rest of the body.

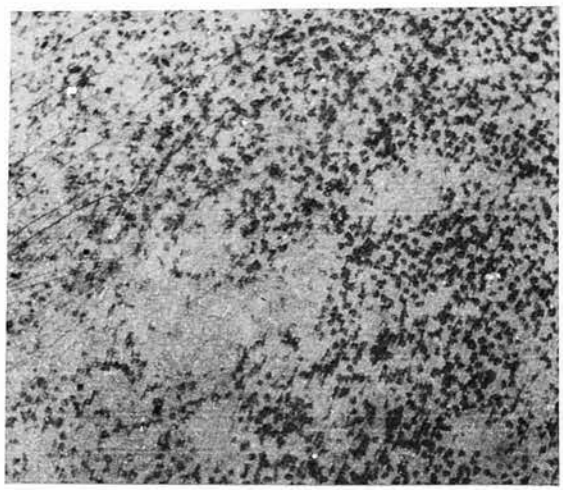


PLATE 5. Sweating in a normal subject at rest demonstrated by gentian violet powder technique (infra-scapular retion). The areas of absence of sweating correspond to areas of active prickly heat.

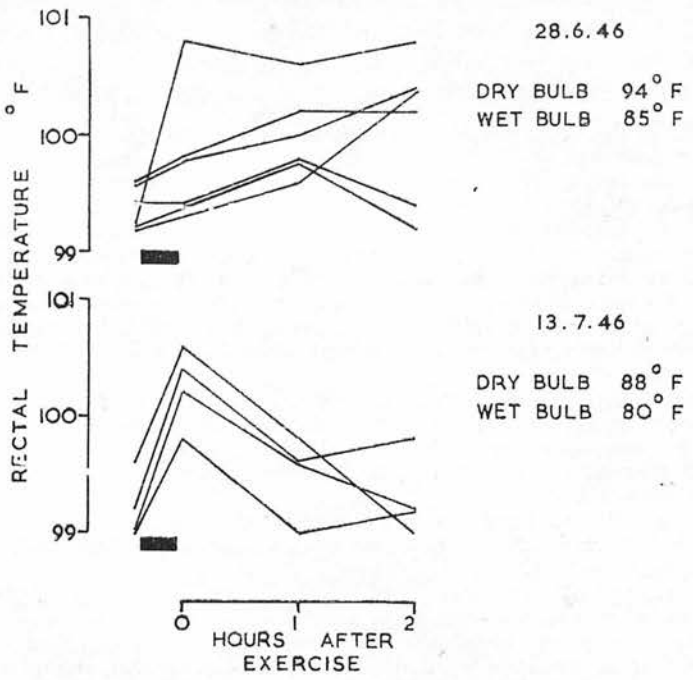
atmosphere of a room in which the dry bulb temperature was 91 deg.F., and the wet bulb temperature 83 deg.F. At rest under these conditions cases of the syndrome showed no sweating on the body, but profuse sweating on the face was a constant feature (plate 4). Plate 5 shows the amount of sweating on the infrascapular region of one of the controls at rest under the same conditions. As a further stimulus to sweating the patients were given a pint of hot tea and sent for a walk in the sun. They still failed to show any sweating on the body or limbs, whereas in the normal controls the streams of sweat washed the dye off the skin.

Two patients with the syndrome were given a subcutaneous injection of carbachol, mg. 0.45. Sweating was not detected on the trunk of either patient, but there was profuse sweating on the face, and both experienced colic and salivation. In two controls, one with a normal skin and one with prickly heat, carbachol produced sweating visible to the naked eye on the trunk and limbs.

In three partially recovered cases an intercostal nerve block was carried out, and, as anticipated, the effect was to abolish whatever small amount of sweating had been demonstrable by exposure to heat.

That the reduction in sweating could lead to a considerable rise in body temperature was shown when patients were given a short period of mild physical training. In spite of the fact that immediately after the exercise they lay down naked on their beds under ceiling fans in the open yard where there was a through draught, their rectal temperatures continued to rise, sometimes for as long as two hours (figure 1). A fort-

night /



The effect of physical exercise on body temperature in anhidrotic heat exhaustion and its dependence on environment. The 20-minute exercise period is indicated by the black rectangle. The subjects of the test were not the same on the two occasions, but were all completely anhidrotic below the neck on clinical examination.

FIG. 1.

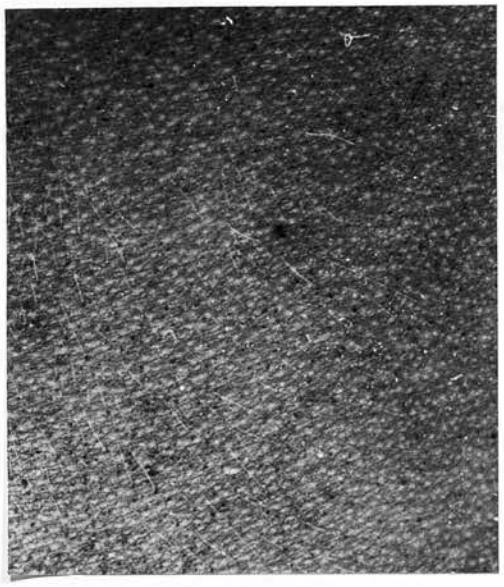
fortnight later the temperature response to exercise was different. The initial rise was greater even in patients who were still anhidrotic, probably because the patients were feeling better and worked harder, but with rest and ventilation the rectal temperatures in the whole group returned rapidly to the base-line (figure 1). The difference in behaviour on the two occasions was largely due to the difference in environmental conditions the temperature gradient between the body and the air being doubled on the second occasion, so greatly increasing the quantity of heat that could be lost by non-evaporative means.

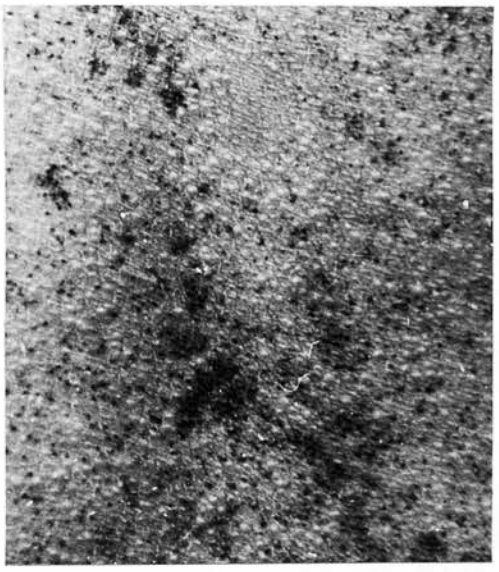
Progress.

On admission to hospital the most seriously affected patients were put into a small air-conditioned side-ward, left there for as long as accommodation was available, and then transferred to the main ward. Vigorous artificial cooling was applied to some cases before it was realised that this was unnecessary.

When it was possible to retain the patients in the air-conditioned ward for several hours the residual symptoms cleared up quickly and the body temperature returned to normal in a few hours, without any relapse on transfer to the main ward. When, on account of overcrowding, it was necessary to treat them in the main ward from the time of admission the response was sometimes slower, especially during the worst period of the hot weather.

Saturation tests with ascorbic acid suggested that the patients, like normal /





PLATES 6 and 7.

Intermediate stages of recovery of sweating after acquired anhidrosis. Two subjects (infra-scapular region after exercise) 4 and 3 weeks after onset of anhidrosis, respectively.

normal controls in the Karachi area, were markedly deficient in vitamin C. Half the patients were thus saturated, but this appeared to have no effect on the rate of recovery as compared with patients who were given no ascorbic acid. Two patients were given massive injections of vitamin A, also without obvious effect.

Progress with regard to sweating function was followed by observations at rest, after drinking a pint of hot tea and after exercise. It is always difficult to assess the actual quantity of sweating, but sweating on the face showed up absence of sweating elsewhere on the body. Sweating usually returned on the limbs before the trunk, thus allowing the collection of sweat for investigation while the greater part of the skin remained anhidrotic. On the body sweating returned first of all in the region of the waist, and last of all over the shoulders.

The slow rate of return of sweating was recorded photographically in three cases by repeating at intervals a standard indoor exercise. Plate 6 shows the incomplete return of sweating three weeks after the onset in one case, and plate 7 the even less complete recovery of sweating four weeks after the onset in another. These plates also demonstrate the scattered distribution of the newly active sweat glands.

The duration of the disease was taken to be the time between the first occasion on which any symptoms of the syndrome appeared and the first occasion on which the skin of the trunk was found to be quite moist after stimulus to sweating. The arithmetic mean and the median of the duration of the disease were each 33 days, with extremes of 13 and 67.

Table /

TABLE III.

Date of onset, interval before admission to hospital and duration of disease (Karachi, 1946).

Date of onset.	Interval in days between first symptoms and admission to hospital.				Duration of disease in days.					
	With additional factor of coincidental disease.	Without additional factor.								
	0–1	0–1	2–6	7 or more.	13–21	22–28	29–35	36–42	43–49	50 and over.
June 3– 9	–	–	–	2	–	–	–	1	–	1
„ 10–16	1	–	2	4	–	–	1	1	3	1
„ 17–23	2	–	6	3	–	3	2	3	2	2
„ 24–30	1	14	6	–	4	8	6	5	–	–
July 1– 7	–	–	2	–	2	–	–	–	–	–
„ 8–14	–	1	–	–	1	–	–	–	–	–
Subjects omitted	One where the date of onset was not recorded, four where the complaint was primarily of skin disease.				One where the date of onset was not recorded, three where the exact date of return of full sweating was not recorded.					

Table III shows the direct relationship between the date of the first symptoms and the duration of the anhidrosis. The earlier in the summer the cases occurred the longer they took to recover. None of the cases had recovered before June 30th, the first cool night for seven weeks. The first case to recover completely did so two weeks later, and the last, four weeks later still. The mean period was four weeks after 30th June, irrespective of the duration of the disease before that date.

Return to duty and follow-up.

It was decided not to discharge patients from hospital until there was a full return of sweating in view of the possible risk of hyperpyrexia. The patients may have been kept in hospital unnecessarily long, and the risk of producing effort syndrome or neurosis in a group of asymptomatic and idle men was appreciated. The decision to discharge the men to duty was not made without misgiving, as there was no evidence to show what would happen if such men were retained under tropical conditions. The two main factors influencing the decision were the possible effect on morale in the area of the repatriation to the United Kingdom of such a large number of men for what appeared to them to be a trivial condition, and the difficulty of getting the patients away from Karachi without exposing them to conditions that might lead to hyperpyrexia.[1] One case was flown home to the United Kingdom eight weeks after the onset of symptoms because he was still completely anhidrotic.

Six /

[1] The sea route to the United Kingdom from Bombay involved rail travel through the Sind desert, where there were very high dry bulb temperatures and the air route involved stops at aerodromes en route where there were also very high temperatures.

Six men were transferred to other areas of India immediately on discharge from hospital. Five remained in hospital for other reasons, and did not relapse. Three weeks after discharge 38 cases were re-examined, all of whom had been continuously on full duty, except one readmitted with ringworm. Many of them had played games of hockey or football, but none complained of any symptoms. Sweating must therefore have been adequate for requirements. All the eight cases originally admitted to sick quarters were also returned to full duty, and none relapsed.

Coincidental disease and complications.

Coincidental disease was found in four patients who complained primarily of symptoms of the syndrome. One of these had active spondylitis, and the unusual degree and duration of pyrexia present could be explained in part by the presence of the heat exhaustion syndrome. One had an exacerbation of chronic bronchitis which cleared up rapidly. One had a large boil that required incision shortly after admission. One had herpes zoster.

One patient who presented a typical history of the syndrome of nine days duration was found to be chloride deficient. On admission the urine contained only a trace of chlorides, and the concentrations on the following days were 0.2, 0.5, and 1.1 gm. per 100 c.c. respectively. He did not complain of heat cramps, and in no way differed from the others in the history of physical signs except for his complaint of abdominal pain.

Four patients reported sick on account of various skin conditions and /

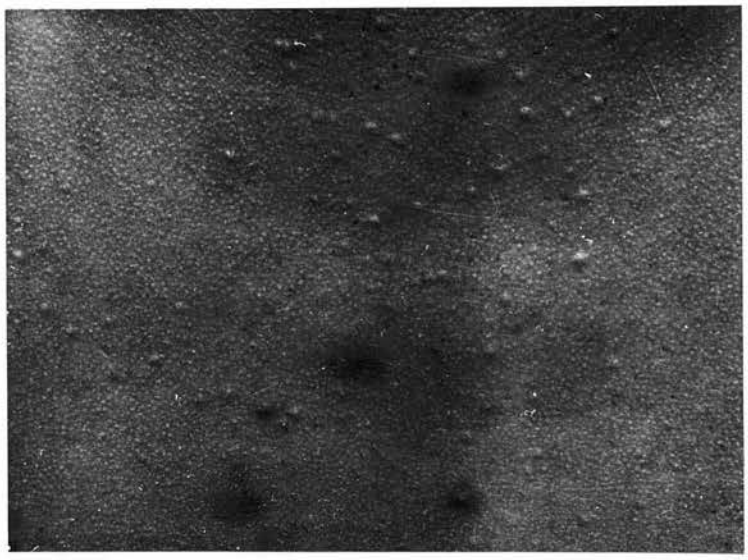


PLATE 8.

Blackheads on front of upper chest, superimposed on mammillaria, during recovery from acquired anhidrosis.

and were found to be cases of the syndrome.

During observation in the ward 20 (40 per cent.) developed pyogenic infections of the skin: 16 cases, a mild hydradenitis, and one case severe enough to require parenteral penicillin; 1 case, sycosis barbae; 3 cases, otitis externa (2 of these also had hydradenitis and are included in the 16 above). Four cases developed prickly heat around the waist when sweating returned. Eleven cases developed acne with blackheads, distributed over the upper part of the front of the chest and back of the shoulders. (plate 8).

Two cases developed malaria (B.T.,relapse) and 2 cases, acute bacillary dysentery. Chemotherapy was started immediately, there was no unusual pyrexia, and the course of the diseases was uneventful.

One patient with anhidrotic heat exhaustion in whom physical exertion had not been an aggravating factor, and who was overweight, was admitted with hyperpyrexia (oral temperature 106 deg.F.). Six other cases had oral temperatures of over 103 deg.F. and one of these had a rectal temperature of 106 deg.F.

One patient (not included in the series) who died suddenly in the ward may have been a case of anhidrotic heat exhaustion, complicated by hyperpyrexia and heat stroke, although it is not possible to exclude a primary pyrexial illness.

Case /

TABLE IV.

Sweat volume and chloride concentrations after standard outdoor exercise.

		1946.				1947.			
		Number.	Mean volume. c.c.	Mean NaCl conc. g. per 100 c.c.	Range of NaCl conc. g. per 100 c.c.	Number.	Mean volume c.c.	Mean NaCl conc. g. per 100 c.c.	Range of NaCl conc. g. per 100 c.c.
Early July ...	Normal	12	11·5	0·28	0·08–0·49	14	8·7	0·24	0·15–0·42
	Mammillaria	6	5·2	0·66	0·40–0·85	6	8·1	0·45	0·32–0·59
	Anhidrotic heat exhaustion (during 1st and 2nd weeks after onset)	19*	3·0	0·73	0·29–0·98	8†	3·1	0·69	0·55–0·78
Late August and early September	Normals	4	8·3	0·21	0·15–0·29	4	8·3	0·25	0·14–0·32
	Anhidrotic heat exhaustion (after clinical recovery)	14	4·7	0·65	0·35–0·89	6	9·3	0·56	0·40–0·70
Summer of succeeding year	Anhidrotic heat exhaustion (recovered)	3‡	12·0	0·18	0·14–0·27	—	—	—	—

* Only 13 cases produced enough sweat for measurement and analysis.

† „ 4 „ „ „ „

‡ One of these subjects (with a sweat chloride of 0·16 g.) developed mammillaria later in the summer in 1947 and then had a sweat chloride of 0·32. g.

Case history. On 17th June, before any clear-cut case of anhidrotic heat exhaustion had been recognised, a very obese and plethoric airman aged 38 years, was admitted to a general ward with the usual non-specific symptoms of a "pyrexia of unknown origin". His oral temperature on admission was 102 deg.F. and it remained in that region until the afternoon of the 19th June. There was no clinical evidence of any disease, apart from the fever, and no malarial parasites were found in frequently repeated blood smears. There was extensive prickly heat and the skin was noted to be hot and dry. There is no evidence about the presence of absence of mammillaria, which had not then been recognised.

During the day of 19th June he was noticed by other patients to visit the lavatory frequently, and in the early evening he became restless, began to walk about the ward in a dazed way, and was difficult to control. He became unconscious in a few minutes and his rectal temperature was then found to be 110 deg.F. He died two hours later in spite of active treatment. A full post-mortem examination failed to reveal any anatomical or infective cause of death.

During 17th to 19th June dry bulb temperatures ranged from 83.5 to 95.5 deg.F. and, in spite of the humidity, it is difficult to imagine that the environmental heat was sufficient to cause heat stroke without some additional factor of disease or anhidrosis.

Biochemical investigations.

Studies of the daily salt and water excretion in cases of anhidrotic heat exhaustion showed no deficiency of either.

Samples of sweat from cases of the syndrome and from normal controls were collected, and the volumes and concentration of chloride are recorded in Table IV. The outstanding feature was the very high chloride concentration of the sweat in cases of anhidrotic heat exhaustion, which persisted even after clinical recovery, but were normal the next summer. A high sweat chloride was also found in subjects with mammillaria although they did not have exhaustion symptoms, so that this finding was not peculiar to the syndrome.

The /

The whole blood and true plasma chlorides in four patients averaged 80.5 and 99.5 mg. per litre, about identical with the values in eleven normals. The haematocrits were 42.1 and 46.4 per cent. respectively. The blood urea of nine patients averaged 27.5 mg. per 100 ml. as compared with 34.5 mg. in fourteen normals.

Fractional test meals (alcohol, without histamine) were carried out in eight patients with the syndrome. Two had complete achlorhydria, and there was certainly no increased secretion of chloride in the others.

Symptomatic sequence.

Careful questioning of the patients revealed that the clearing up of prickly heat, the development of mammillaria and the reduction in sweating occurred more or less together. The exhaustion symptoms never preceded the reduction in sweating. In over half the cases they were thought to be coincidental, in 14 cases (31 per cent.) there was an interval of up to four days before exhaustion symptoms appeared, and in 3 cases (7 per cent.) the interval was more than ten days. The interval between the reduction in sweating and the date of admission to hospital varied, but as the peak of the hot season (last week in June) approached the interval became shorter (Table III, page 140).

The case histories thus showed that there was a constant sequence of events - first prickly heat; then clearing up of prickly heat with reduction in sweating and appearance of mammillaria; and lastly, onset of constitutional symptoms. The historical evidence was confirmed by direct /

direct observation at each stage in an individual who was visiting the Hospital at intervals as an out-patient for an unrelated condition. The constancy of this symptomatic sequence exhibited by the patients is evidence in support of the view that sweating deficiency is the pathological basis of the syndrome.

Case 7. This soldier had been put into a limited medical category in August 1945 on account of "chronic bronchitis" and was referred to the hospital on 21st June for review. There was no recent history of any attacks of bronchitis or any other significant symptom, except a slight and gradual loss of weight since arrival in Karachi about six months previously. He had survived the previous hot season uneventfully. Physical examination revealed only a few scattered rhonchi in the lungs, and an X-Ray subsequently revealed normal lung fields. It was noted at the time that severe active prickly heat was present and a towel was required to dry the chest before the examination could be carried out.

He reported again on 2nd July for a final disposal after the X-Ray had been viewed, and it was noticed that the prickly heat had begun to clear up and that mammillaria was present. He stated that on June 30th the prickly heat had started to clear up, and sweating to be much reduced. This was confirmed on examination. When he was examined again on 4th July he stated that the skin had felt "clammy" during the journey to the hospital in a lorry, but proper sweating had been absent for several days except for the face which was sweating at rest; the skin was found to be quite dry, and sweating was not produced on exercise.

He would not admit to any feeling of mental or physical exhaustion, headaches, dizziness, or dyspnoea, but frequency and polyuria had been present since the onset of the reduced sweating. There had been no cramps in the abdomen or limbs. He had not increased his fluid or salt intake (one large teaspoonful daily). Up to 28th June he had been employed as a mess waiter, and since then on outdoor sanitation duties, but neither involved hard physical work.

Exhaustion symptoms were readily produced on exertion, accompanied by profuse sweating on the face only. On admission to the ward the oral temperature was 99 deg.F., and the urine contained 0.8 g. per cent. chlorides.

Aetiological factors.

None of the patients had congenital absence of sweat glands. The anhidrosis was acquired and the fact that, with three exceptions, all the cases had been in the area continuously for the preceding four months, suggested that an uninterrupted exposure to environmental heat was a major aetiological factor. There was a different incidence of anhidrotic heat exhaustion in coastal and inland camps, which is discussed later. In a search for factors which might have made the patients more susceptible the following were eliminated: age, weight and complexion, the distribution of all of which was the same in controls as in the patients. Recent illness had not occurred in any of the patients, and all of them had suffered relatively lightly from tropical diseases. Prickly heat was an invariable feature, but this did not distinguish them from the rest of the Service population in the Karachi area, among whom prickly heat was very common. The following findings were apparently relevant:

All 58 patients were "other ranks". One officer was reported to have the syndrome early in June, but was not seen. It is known that no other officers had the syndrome.

A very large variety of indoor and outdoor occupations was represented. While the exact distribution of occupations in the units in the area was not known, analysis revealed that the highest incidence occurred among a pioneer company whose personnel undertook a considerable amount of physical work. There was only one cook in the series in spite of the particularly hot environment in which the cooks worked.

The /

TABLE V.

Comparative incidence of anhidrotic heat exhaustion to show differences among camps and units.

Site.	Number at risk to nearest hundred.	Number of cases.	Incidence (cases per 1,000).		
			Total.	R.A.F.	Army.
A. Mauripur...	2,200	26	12	9	39 (pioneer company)
B. Karachi ...	1,200	20	17	4	24 (airborne infantry) 20 (all other troops)
C. Drigh Road	1,200	5	4	4	—
D. Malir ...	1,500	4	3	—	2 (airborne infantry) 3 (all other troops)
E. Manora ...	(About 10)	—	—	—	—

Three patients are omitted in whom the symptoms began within the first few days of their arrival in Karachi. Officers are omitted from the numbers at risk as the table is designed to distinguish the effect of physical exertion, as well as that of climate.

The incidence in the Army was much higher than in the R.A.F. (Table V). The soldier's life in airborne infantry and pioneer units was more arduous than the airman's at a base maintenance unit and transport aerodrome. The pioneer company also had the highest incidence of skin disease and dysentery. This unit, unlike all others, lived under canvas and also under less hygienic conditions than the other units. This and other evidence suggested that a nutritional factor might be important, but analysis of food intake showed no deficiency, except possibly of ascorbic acid. As recorded, saturation with ascorbic acid and with vitamin A appeared to have no therapeutic effect.

The general level of intelligence of the patients seemed to be inferior to that of patients in the other wards of the hospital. This impression may have been gained as a result of the repeated cross-examinations necessary to obtain reliable and detailed histories, but even allowing for this the impression remained that the men were more stupid and dull than the average Service patients in hospital.

CLINICAL MATERIAL, 1947.

During the summer of 1947 eight cases of anhidrotic heat exhaustion and collapse were seen. All of them gave a history of having had prickly heat, and all showed mammillaria. Only four cases occurred in the area during the whole of the summer. In the first two cases symptoms were precipitated by a period of heat unusual for the area, when the maximum dry bulb temperature was 101, 108, 110 and 107 deg.F. respectively, on four successive days. These two cases were found to be not completely dry: stimulation by heating on the day after admission produced a limited amount of sweating on the trunk. In contrast to completely anhidrotic cases, exposure to heat also produced erythema of the skin. The symptoms in the third case had begun at the same time as the first two, but he did not report sick until ten days later. He was then completely anhidrotic even on exposure to heat. In all three cases the onset of symptoms was gradual.

The fourth case was not admitted until much later, when the weather was cooler, and began with an attack while he was working in the cabin of a lorry with the engine running, where carbon monoxide may have been a contributory factor as well as the heat of the engine. In this case sweating was still present on the buttocks and thighs on admission, but subsequently /

subsequently these areas also became anhidrotic.

Two of the four cases complained of polyuria and frequency of micturition. In one of these micturition occurred every fifteen minutes for several hours, and on one occasion every five minutes for half an hour. The other case commented on the urgency of micturition, and difficulty in retaining urine. Hyperventilation was a prominent symptom in this case, even overnight.

The other four cases occurred at Cawnpore, and were transferred by air to the Hospital at Karachi. They were still almost completely anhidrotic when they arrived, and in one of them there was no sweating on the forehead or face even after exposure to severe heat strain.

All of the eight cases were retained in hospital. Two of them lived in an air-conditioned ward for ten days, but this did not influence the rate of return of sweating. In the completely anhidrotic subjects sweating first returned around the waist. At this stage observations were made after the intradermal injection of a 1 : 10 solution of carbachol (mg.5 per 100 c.c.). Sweating appeared locally when the injection was made round the waist but not when it was made elsewhere on the trunk. The parallelism between the local action of carbachol and the exercise tests confirmed that the latter was an adequate test of secretory power of the sweat glands. In the early stages of febrile conditions encountered at Karachi, such as malaria and dengue, when the skin was hot and dry, injection of diluted carbachol immediately under the skin produced local sweating, as in normals.

Acute /

Acute attacks of the syndrome could be reproduced in these otherwise symptomless cases by means of an indoor exercise test. The patients showed marked breathlessness and tachycardia and could easily be brought almost to the point of collapse, but they did not differ from normal subjects under the same conditions, except that the latter required more strenuous and prolonged exercise to reach a corresponding state of collapse.

As in 1946, sweating returned on the limbs before the trunk, except in one individual where no sweat was obtained from the arm for more than a week after sweating had returned on the trunk. In six of the eight cases the average duration of the anhidrosis was seven weeks. One of the cases from Cawnpore was still completely anhidrotic three months after the onset, although at one time slight sweating had returned for a few weeks, and he was evacuated to the United Kingdom by air, along with the fourth case from Karachi, who had then been anhidrotic for two weeks.

The sweat chloride in all the cases was abnormally high (Table IV). The raised chloride again persisted after clinical recovery, and two months later a considerably lower, though still abnormal, value was found. Intelligence tests conducted on seven of the eight cases showed that, as a group, they were of a lower standard than that of men undergoing the same tests for vocational guidance.

The clinical picture of the "epidemic" of 1946 and of the cases in 1947 was very uniform except that in 1947 the reduction in sweating on the trunk was sometimes only partial instead of being complete as in 1946. As the degree of reduction of sweating required to produce symptoms depends /

depends to a great extent on the environmental temperature, it is believed that the higher maximum temperatures of 1947 were responsible for the occurrence of symptoms with only a partial reduction of sweating.

ASYMPTOMATIC SWEATING DEFICIENCY (HYPHIDROSIS).

In the latter part of the hot season it was possible to pick out individuals with mammillaria and reduced sweating on the trunk before making any careful examination, because of the obviously increased sweating in other areas. Such individuals were sweating profusely on the face under conditions when normals were not, and under greater heat stress sweat was seen soaking through their trousers while their tunics remained dry. These individuals were considered to be "hyphidrotic" in spite of the compensatory increase of sweating, because, even although the total volume of sweat produced in a given time may not have been reduced, the area over which evaporation could be effective was limited, especially in the sitting position. Several of these men were able to continue a very active life (including, in some cases, route marches) in spite of their hyphidrotic state, just as in 1946 complete anhidrosis could be present without overt symptoms. The rate of return of full sweating on the trunk in those who were hyphidrotic and had never had symptoms of anhidrotic heat exhaustion seemed to be more rapid than in those who had never developed symptoms as a result of deficient sweating.

Subjects /

Subjects with hyphidrosis showed severe mammillaria and the changes in the sweat composition associated with this. In two cases of this type, where accurate weight records are available, there was a rapid loss of weight immediately after the onset of hyphidrosis (125 lbs. to 118 lbs., and 130½ lbs. to 127 lbs., respectively, in 12 days). The new weight level was maintained as sweating returned.

RELAPSE AND RECURRENCE OF THE SYNDROME.

None of the cases of anhidrotic heat exhaustion at Karachi relapsed but in both 1946 and 1947 the climatic conditions had improved considerably by the time the patients were discharged from hospital. The three men who had the syndrome in 1946 and remained in Karachi did not develop the syndrome in the following summer. The syndrome can, however, occur in the same individual in a subsequent hot season. Histories obtained from two of the patients in the 1946 series showed that they had undoubtedly suffered from the same syndrome during the previous summer in another part of India, although it had not been recognised as such

Case 8. This soldier had had severe prickly heat in Bilaspur (in eastern Bengal) the previous summer. In the last week of June 1945 he had travelled by train to Karachi, a journey occupying seven days, and during this time his prickly heat had cleared up completely in spite of the severe climatic conditions, and the train journey. While on the journey he complained of severe exhaustion symptoms and of polyuria and frequency of micturition. He did not sweat for about a month after he arrived in Karachi, and although he did not know if he had a raised temperature, he admitted to having felt very hot. His general symptoms persisted but by means of "dodging /

"dodging work" he was able to avoid reporting sick. He did not want to complain, because he knew of another soldier in his unit who had the same symptoms and whose temperature was known to be raised at midday, but who had been prescribed "medicine and duty" and had not even been excused any work. Both men apparently completely recovered.

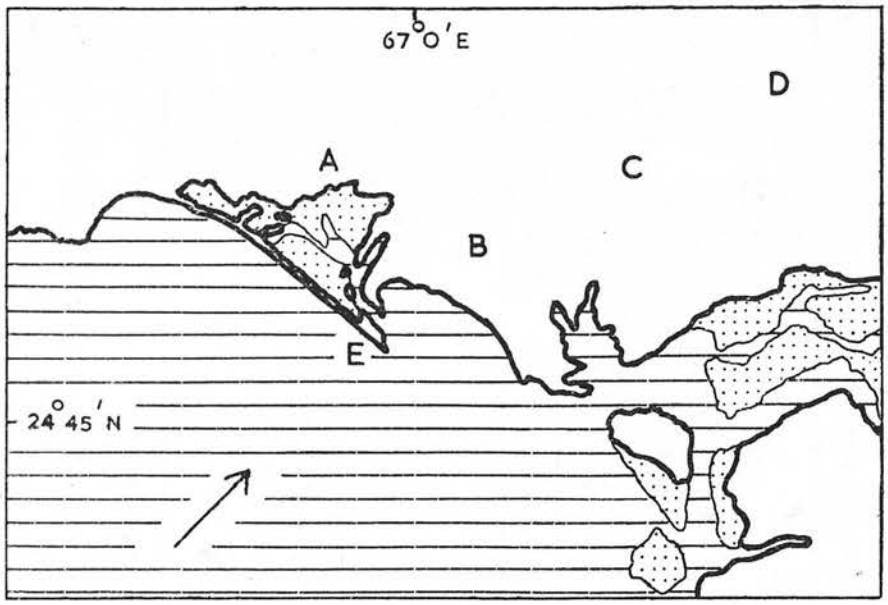
Case 9. This soldier had had "septic" prickly heat at Bilaspur in the summer of 1945 and had had attacks of cessation of sweating, usually precipitated by a game of football. When he reported sick, he was always found to have a raised temperature but after lying down for several hours felt all right. He was apparently not doing any work at that time. The symptoms cleared up as the weather became cooler. He knew of two others in his unit who complained of the same condition: one was seen by a specialist and prescribed "light duty", and the other was retained in hospital and returned to duty when the weather was cooler.

Some of their friends too appeared to have had the syndrome, and it was interesting that not all of them had required to report sick. Some of them had found it possible by "dodging work" to keep the severity of the symptoms within bounds.

Case 10. After a clinical meeting held in the Hospital at Karachi, at which patients with the syndrome were demonstrated, one of the audience, an R.A.M.C. officer attached to an Airborne Division, remarked that he had been particularly interested to hear the syndrome described, as he now realised that he had suffered from it during the previous summer of 1945.

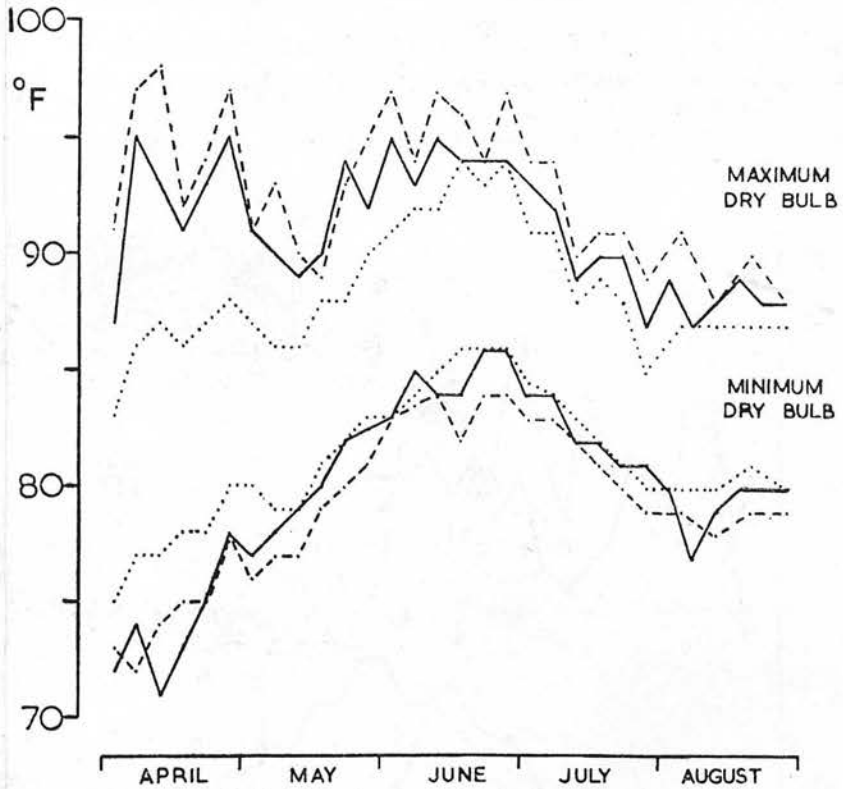
During that summer he had undergone intensive training in India in preparation for the proposed invasion of Malaya, and had been sent to Ceylon to await the event. Soon after his arrival there, to his disgust, he began to feel easily tired and generally unfit. He noticed that his skin was dry and that he had stopped sweating, so he too played a game of hockey in an attempt to restore sweating, but had to give up from sheer exhaustion before the end of the game.

After that he used to lie all day in his tent, wondering what would happen when he did have to do something really strenuous and invade Malaya, but fortunately the Japanese surrender saved him from putting /



Sketch map of the Karachi district to show the position of the military camps and aerodromes. Scale 4 miles to 1 inch. The arrow shows the direction of the prevailing wind during the summer.

FIG. 2



—Comparative meteorological data for three sites A, C and E. (a) 1946. Site C - - - - - - - Site A ———— Site E .....

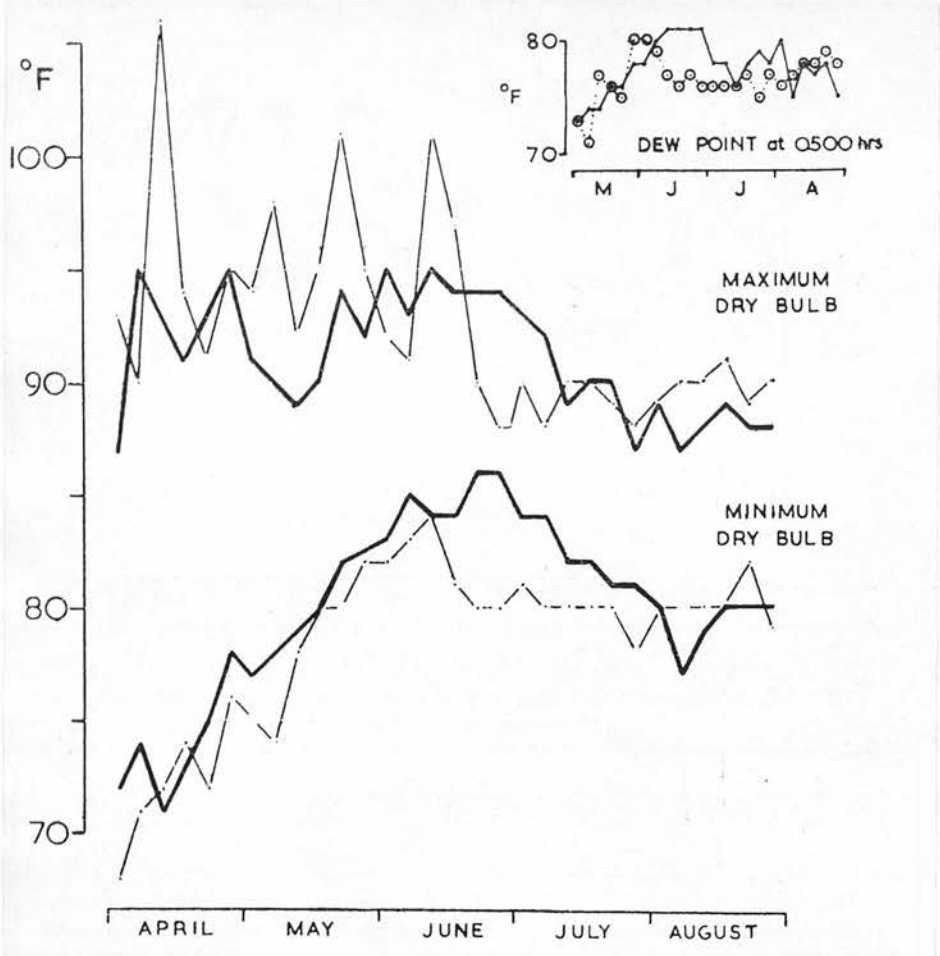
FIG. 3.

putting this to the test. He recalled that he had had severe prickly heat while in India and that it had cleared up when he arrived in Ceylon. There was no recurrence of the syndrome during 1946.

THE CLIMATIC FACTOR IN ANHIDROTIC HEAT EXHAUSTION.

In 1946 the incidence of anhidrotic heat exhaustion varied considerably from camp to camp in the Karachi area, both for the R.A.F. and for the Army (Table V). The sites of the camps are indicated in a sketch map (figure 2). At three of them regular meteorological observations were made (figure 3). It is clear that the more inland the camp the higher the daily maximum temperatures and the lower the minimum dry bulb and wet bulb temperatures. This change with distance from the sea is what would be expected since 100 miles inland the climate is typical of the desert with very high daily maxima, low minima and low humidity, but the trend could be demonstrated even over the short distance of 10 miles between sites E and C. Unfortunately, meteorological observations were not made at site D but it is safe to assume that, as it was the farthest inland of the sites it was also the driest and hottest of them all.

In 1947 there were the same meteorological differences among different camps, and although there were far fewer cases of the syndrome, all occurred in the coastal area. As in 1946, therefore, there was higher incidence of anhidrotic heat exhaustion in the areas with the higher humidity and /



4.—Comparative meteorological data for Karachi 1946 and 1947. The bolder line in each case is 1946.

FIG. 4.

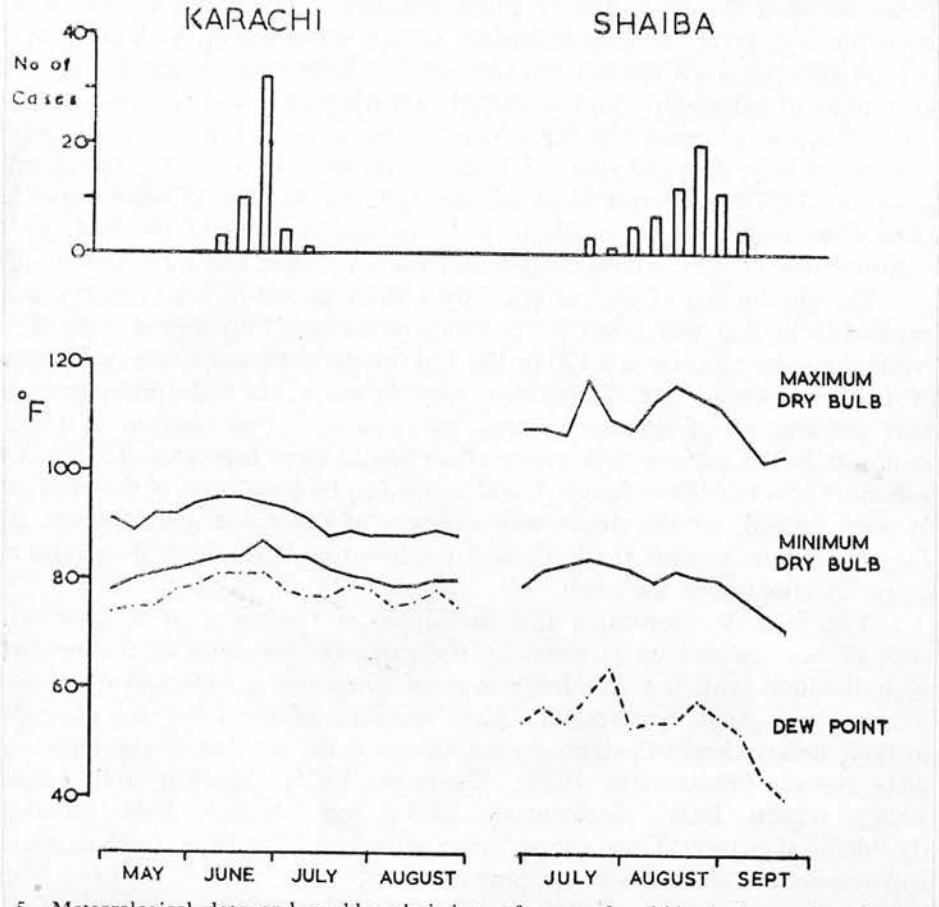


FIG. 5.

5.—Meteorological data and weekly admissions of cases of anhidrotic heat exhaustion at Karachi, 1946 (original data) and Shaiba, 1943 (redrawn from LADELL et al. 1944).

and minimum temperatures, but lower maximum. The difference in total incidence between the 2 years also suggests that the maximum temperature is not the crucial climatic factor since in 1947 the lower incidence was associated with a higher maximum temperature (figure 4), and again the lower incidence was associated with a lower minimum temperature. Nevertheless, if the differences in incidence between 1946 and 1947 and between the different camps, were really due to differences in the minimum temperature or the humidity or both, then small differences of some 5 deg.F. must have been of considerable importance.

There is further evidence in support of the conclusion that the minimum temperature may be a significant environmental factor. The meteorological data and incidence of cases of anhidrotic heat exhaustion at Shaiba ("heat exhaustion type 11" of Ladell et al.,1944) is given in figure 5, together with the corresponding data from Karachi. The minimum dry bulb temperature is the only environmental feature at all comparable at the two places. Cases of the same syndrome at Cawnpore, India, in 1947, occurred in two groups corresponding to the two peaks of minimum dry bulb temperature.

Thus in four separate comparisons the incidence of anhidrotic heat exhaustion appeared to depend on the minimum air temperature.

A COMPARISON /

A COMPARISON OF THE DIFFERENT ACCOUNTS OF THE SYNDROME.

The wide geographical distribution of cases has already been noted, and the similarities and discrepancies among the principal accounts of the syndrome (Allen and O'Brien,1944, Wolkin et al.,1944, and Ladell et al. 1944) were discussed by Waterlow (1945) and O'Brien (1948). All the authors are agreed that the main symptoms of the syndrome were those of physical and mental asthenia or exhaustion, aggravated by exposure to heat, especially if accompanied by physical exertion, and relieved by rest and cooling. It was also agreed that the body temperature usually was raised, and that sweating was not impaired on the forehead and face, but there was not the same agreement about the occurrence of anhidrosis on the body and the importance to be attached to it.

At Karachi the evidence for anhidrosis was conclusive and it was also clear that this anhidrosis was responsible for the syndrome. Symptoms followed anhidrosis, never preceded it, and could be reproduced by appropriate measures until the time that sweating returned. There was no evidence of toxaemia and, except when coincidental disease was present, the body temperature at rest remained normal and the patients were then symptom free. The symptoms of exhaustion, undue warmth, breathlessness and distress, and even a diuresis, can be produced experimentally in normal subjects on exposure to heat, especially if evaporation of sweat is prevented by immersion in water (Bazett,1927). A great deal of the symptomatology of anhidrotic heat exhaustion may thus be ascribed to the normal reaction of the body to the accumulation of heat, which would otherwise have /

have been lost by evaporation.

The production of an "attack" by a short period of hard exercise is not explicable in this way, since body temperature was only raised 1 to 2 deg.F. while the pulse rate reached 170 to 180, and the patient was extremely distressed. Normal subjects reacted in the same way, however, the only difference being that the amount of exercise needed was greater. This element of physical unfitness in the patients was greater than would have been expected from the softening effect of life in hospital, and seemed to be a real part of the syndrome. It may indeed be the direct consequences of the sweat gland failure also; for example, in normals the lactic acid produced by hard physical exercise may be partly removed in the sweat.

The final demonstration that anhidrosis is the cause of this particular type of heat exhaustion is given by the exact reproduction of the syndrome in individuals with the anhidrotic type of congenital ectodermal dysplasia in which sweat glands are absent. Most accounts of the latter are incomplete in their descriptions of symptoms but the cumulative effect of the more complete reports (Thurnham,1848; Tendlau,1902; MacKee and Andrews,1924; Weech,1929; Sunderman,1941; and Felsher,1944) establishes the identical nature of the symptoms experienced by subjects with congenital and acquired anhidrosis when exposed to heat.

Allen and O'Brien (1944) also concluded that anhidrosis was the fundamental lesion. In the humid climate of Northern Australia and New Guinea all the cases showed the same complete and uniform dryness of the body /

body as was observed at Karachi in 1946. In the hotter and drier climates of Shaiba and of the American desert the deficiency in sweating was less complete. Although Wolkin et al.(1944) found "almost complete anhidrosis below the neck", sometimes "isolated islands of sweat appeared over the abdomen and legs" on exposure to the sun and after administration of sudorific drugs, and, although in their summary of case histories they used the phrase "loss of sweating", the individual histories indicate that sweating was usually diminished, not absent.

Ladell et al.(1944) stated that their patients at Shaiba varied considerably in the degree of sweating found on examination and described a patchy distribution of defective sweating. "The chest was usually moister than the back and the belly moister than the chest. A few cases were dry all over". Thus the nature of their clinical material led to a very guarded approach to the acceptance of anhidrosis as the essential lesion of the syndrome, and the name selected for the syndrome at Shaiba is the only one that does not include a reference to "anhidrosis". "It was necessary therefore to examine more closely the question 'was sweating really defective?'" "A history of defective sweating was given by nearly all patients in this group. It was difficult to put this claim to the test" (Ladell et al.,1944). Moreover when sweating was measured by weight loss their patients showed only a 25 per cent. reduction compared with controls. Sulzberger et al. (1946) were also unable to discover any sweat deficit by measurement of fluid intake and urine output, but at the time of the measurements there was clinical evidence of the return /

return of sweating.

The accurate measurement of sweat volume is always difficult and requires special apparatus. Accuracy of measurement, however, may often be irrelevant as, except under artificial conditions, a proportion of the sweat falls off the body and fails to contribute to heat loss. Clinical examination of the whole patient is the only readily available method and examination by hand and eye or with special techniques such as gentian violet powder enables sweat production to be roughly graded.[1] Indoor exercise tests may be of additional value because then the degree of sweating can be assessed under conditions where there is the minimum of evaporation. Even exercise tests may have to be interpreted with caution, however, because of the latent period before sweating begins and because the rate of sweating diminishes as the exercise continues. The efficiency of sweating as a means of losing heat can, of course, finally be judged only by the overall response of the individual to heat strain, although this response must also depend on circulatory and other factors.

When an individual appears to have a reduced production of sweat, but is able to continue his work in the climatic conditions prevailing, it must be assumed that his sweating is adequate. When complete anhidrosis is present there are certain obvious limitations to the environment in which the individual will remain free of symptoms. At rest, or on taking only mild physical exercise he will have no symptoms, unless the dry bulb exceeds a temperature of the order of 85 deg.F. With an increase in heat production /

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[1] Experiments discussed in chapter 12 suggest that the visibility of sweat droplets on the skin depends on its fat content.

production or an increase in environmental temperature symptoms will develop, The threshold will depend to some extent on psychological factors, and the severity of the symptoms on the stress imposed by the excess of heat generated over the amount of cooling possible by non-evaporative means.

The same principle applies when sweat production is diminished, not absent, except that the stress required to produce symptoms will be increased according to the amount of effective sweating remaining. Thus in a desert climate, as at Shaiba, with a high environmental temperature, individuals with a partial sweating deficiency are likely to have symptoms, and in view of the difficulties in assessing sweat production it may not be easy to show that a reduction in sweating is the cause of the symptoms. Particular circumstances may be crucial in determining the onset; for instance, an individual with reduced sweating on the trunk and a compensatory increase in sweating over his buttocks and thighs will reduce evaporation from those areas by sitting in the cabin of a truck and may thus precipitate symptoms due to insufficient loss of heat. In contrast, at Karachi in 1946 when the environmental temperature was relatively low, symptoms occurred only when there was complete bodily anhidrosis and even then not invariably, thus simplifying the understanding of the syndrome. In 1947, on the other hand, which was hotter and drier than 1946, Karachi was more like Shaiba, and individuals with only a partial reduction in sweating showed the full symptoms of anhidrotic heat exhaustion. Thus the occurrence in desert climates of cases with only a partial reduction in /

in sweating actually supports the conclusion that the fundamental lesion of the syndrome is a deficiency in the production of sweat.

Other points of apparent disagreement among the different accounts can also be resolved by consideration of other ways in which climate modifies signs and symptoms and by interpretation of the way in which they are described.

A history of preceding prickly heat. This was noted in all accounts except that of Wolkin et al.(1944) who mentioned it in one case history only. They stated, however, that a profuse outpouring of sweat often preceded the anhidrosis. If profuse sweating was common it may be that prickly heat was also common and perhaps not considered worthy of comment.

Time relationship of onset of anhidrosis and improvement in prickly heat.

Although at Shaiba 80 per cent. of the patients were stated to have severe or moderately severe prickly heat on admission to hospital, i.e. after onset of symptoms due to reduced sweating, it is clear from the reference to desquamation that the prickly heat was in the healing stage, as it also was at Karachi.

The statement of Allen and O'Brien (1944) that the prickly heat rash "disappeared three to four weeks before the anhidrosis supervened" is difficult to explain, unless it is assumed that by "anhidrosis" they meant the general symptoms of the anhidrotic type of heat exhaustion. This delay in the onset of general symptoms would fit in with the relatively mild climatic conditions of the district in which their cases were seen as /

as compared with the other areas (Waterlow, 1945).

Polyuria and frequency of micturition.

The stress laid on these symptoms was very varied. They were emphasised by Ladell et al.(1944) but Allen and O'Brien (1944) stated that their cases showed no urinary symptoms. At Karachi the symptoms were very prominent in some individuals but were quite often absent. Interpretation of the symptoms was difficult too, because many patients were conscientiously following advice to take more fluid. It is clear from some of the case-histories that this was not the only cause for the polyuria and frequency of micturition, and other possible causes are numerous. The habit of drinking may persist even when sweating has ceased and with it the original stimulus to drink, as suggested by Ladell et al.(1944). These urinary symptoms are discussed more fully in chapter 8 but the multiplicity of factors involved and the paucity of relevant information make it impossible to be sure of the exact place they have in the clinical picture of anhidrotic heat exhaustion, or of the way climate may modify their occurrence.

Changes in the skin.

A general pallor of the skin was noted by Allen and O'Brien (1944) as well as at Karachi, but Ladell et al. (1944) described the colour of the skin as red. A flushed skin was also seen at Karachi in 1947 in the two cases whose symptoms were precipitated by a high environmental temperature and who also resembled the cases at Shaiba in showing only a partial deficiency in sweating.

Mammillaria /

Mammillaria was not noted by Ladell et al.(1944), but it is possible that its presence was concealed by the abundant desquamation present in 80 per cent. of their patients on admission. The abundance of the desquamation at Shaiba as compared with Karachi may have been another consequence of the hotter and drier climate of Shaiba. Further the considerable degree of lichenification which was often seen at Shaiba after the disappearance of the desquamation and which occurred most markedly on the back may have been a change analogous to mammillaria (Waterlow, personal communication, 1947).

That mammillaria may not be an invariable feature of anhidrotic heat exhaustion, however, is suggested by the observations of Dr. Thomas Parkinson (personal communication 1946), who saw cases of the syndrome both in a humid climate (Ceylon), and a dry one (Cawnpore, India). The former were typical of those seen at Karachi. At Cawnpore, where before the monsoon the climate resembles that of Shaiba and heat stroke and chloride-deficiency are prevalent, the cases of anhidrotic heat exhaustion resembled those at Shaiba in the rapid return of sweating (usually in ten days), and the liability of relapse even after sweating had apparently returned. Further, mammillaria was seen in only eight out of fourteen cases, usually with desquamation, and in two cases desquamation was the only abnormal change. Thus mammillaria, although looked for by an observer familiar with its appearance, was not a constant feature, and it seems likely that in this respect also climate can modify the syndrome of anhidrotic heat exhaustion. Dr. M. A. Floyer, who also saw cases in both types /

types of climate (Karachi and Cawnpore, 1947), confirmed the absence of mammillaria in a proportion of cases of anhidrotic heat exhaustion at Cawnpore. In cases occurring in a humid climate, however, mammillaria appears to be invariable.

Investigations.

The differences between the various observers in their interpretation of skin biopsies are discussed in chapter 12 . At Karachi blood and plasma chlorides were normal, at Shaiba they were reduced (Ladell et al. 1944). These differences may also be related to climatic differences because the lower chloride values were obtained in an area where chloride deficiency was common. The blood urea was less than that in normals at both Karachi and Shaiba. The various investigations of sweating function have already been discussed.

The difference in clinical picture during and after "attacks".

Some other discrepancies in the different accounts may be resolved by considering how the observations were modified by the time when the cases were seen, for example, during or after recovery from an "attack", especially if actual collapse had occurred. Allen and O'Brien (1944) made observations "during or shortly after an attack", whereas it is clear that those of Ladell et al.(1944), like the majority of those at Karachi, were made in hospital and after recovery from an attack. Wolkin et al. (1944) first saw their cases after admission to hospital but their detailed histories describe typical attacks. The description of an extremely /

extremely distressed and anxious patient, with a high pulse rate and marked dyspnoea does not apply to a patient who has been rested and cooled for a short period, as pointed out by Allen and O'Brien (1944).

Other signs and symptoms.

Allen and O'Brien (1944) noticed enlargement of axillary and inguinal lymph glands. In most cases they were moderately enlarged and tender, but not painful, and they did not persist for more than a few days. Sulzberger et al. (1946) showed in one case that prolonged exertion resulted in tenderness of lymph glands. At Karachi in 1946, when lymph nodes were not specifically examined, one case was noted to have a transient enlargement. In 1947 no enlargement of lymphatic glands was noted after short periods of exposure to heat strain. Lymph gland enlargement was not mentioned by Ladell et al. (1944) or Wolkin et al. (1944).

Allen and O'Brien (1944) also observed that the limbs could be so swollen that the natural folds and increases were obliterated. This was not observed at Karachi, and is not mentioned in the other reports, but comparison of plates 2 and 3 in the paper by Sulzberger et al. (1946) suggests that skin creases disappeared on exertion.

Sulzberger and Zimmerman (1946) noted that the skin of their case was very resistant to keratolytics. The skin of subjects with mammillaria was also resistant to keratolytics (O'Brien, 1947). At Karachi one case of mammillaria was able to tolerate the application of 20 per cent. salicylic acid in collodion daily for several successive days without there being any apparent change in the skin.

Progress /

Progress, complications and relapses.

At Karachi sweating returned on the limbs before the trunk almost invariably, whereas in Australasia the opposite was true (Allen and O'Brien 1946). In Australasia and Karachi complete recovery took many weeks. The statement of Wolkin et al. (1944) that recovery of normal sweating function took place relatively rapidly clearly refers to the period elapsing after admission to hospital. If the duration of the disease is taken to be the period from the onset of symptoms to the return of sweating, it is possible to discover from the histories that recovery in five of their cases took approximately 60, 30, 24, 22 and 12 days respectively (mean 30 days). In two cases the period is uncertain, and in the last case recovery of sweating took place within twenty-four hours of the onset of symptoms, making it unlikely that this was a true case of the syndrome. At Shaiba the cases were in hospital for a shorter time but recurrences were frequent and caused great loss of time and efficiency (Waterlow, personal communication, 1947).

At Karachi several cases of anhidrotic heat exhaustion had high body temperatures, and a fatal case of heat stroke, probably secondary to anhidrosis, was seen. Ladell et al.(1944) refer to one patient who developed a temperature of 105 deg.F. for no accountable reason while in the ward. Parkinson (personal communication 1946) at Cawnpore, saw a case of anhidrotic heat exhaustion with hyperpyrexia and in coma, i.e. complicated by heat stroke. There is therefore clinical confirmation of the /

the danger of hyperpyrexia and consequently of heat stroke in cases of anhidrotic heat exhaustion.

The tendency to relapse noted by Ladell et al.(1944) was probably due partly to the incomplete return of sweating when their cases were discharged from hospital, and partly to the effect of a desert climate in producing symptoms with only partial impairment of sweating.

The high incidence of skin sepsis in the series at Karachi was in keeping with the high incidence among the whole Service population and may not have been directly related to the syndrome, but as in other series skin sepsis was emphasised, it may nevertheless be a true complication.

Conclusion.

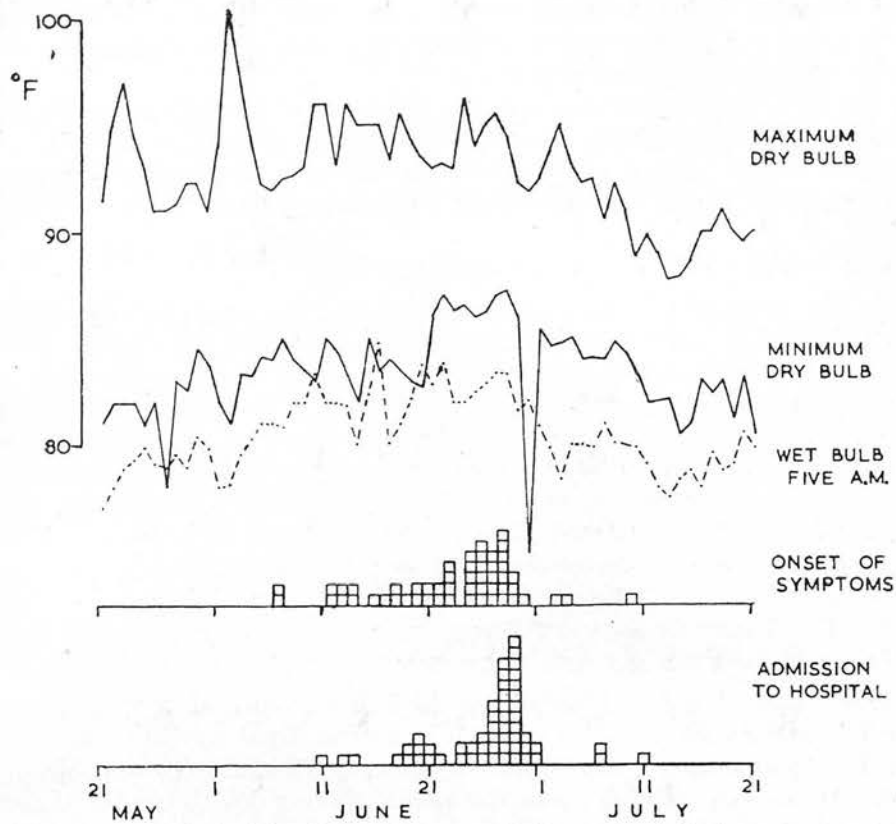
It was stated at the beginning (without proof) that the various reports referred to there were in fact accounts of one and the same syndrome although there were discrepancies which were difficult to reconcile with this view. A detailed review of these discrepancies has established the major points that the degree of sweating deficiency necessary for symptoms depends on environmental temperature, so that complete anhidrosis is an inconstant feature, and that the skin change called mammillaria may also be absent in a desert climate. There seems no longer any doubt of the identity of the syndrome described by the various authors.

THE /

THE RELATION BETWEEN ENVIRONMENT, THE APPEARANCE OF SYMPTOMS AND THE CAUSATION OF THE ANHIDROSIS.

It has been concluded that the syndrome of anhidrotic heat exhaustion is a consequence of a reduction in sweat production. Anhidrosis may be congenital in origin or acquired, but all the cases of anhidrotic heat exhaustion discussed belonged to the latter group. Very few cases of acquired anhidrosis have ever been reported from temperate zones and in them the cause has either been a generalised exfoliative dermatitis (Fox, personal communication, 1949) or a serious illness, like enteric fever (Engelhardt and Melvin, 1945). In the cases of anhidrotic heat exhaustion at Karachi and Cawnpore the anhidrosis was due to neither of these causes and the conclusion seemed unavoidable that the anhidrosis was produced by the environment in which the cases occurred. Clinical observation can provide no absolute proof and a discussion is inevitably difficult and involved because of the necessity for distinguishing the causation of anhidrosis by environment from the production of symptoms by environment in an individual who is already anhidrotic.

When the secretion of sweat is diminished or fails, whatever the cause, the body loses its ability to increase heat loss by increasing evaporation, and the maximum amount of heat that can be lost is fixed by the environment, not by the body. Heat loss by radiation, convection and /



Daily meteorological data for site A and case incidence of anhidrotic heat exhaustion at Karachi in 1946. Each square represents one case. The dates of onset of symptoms and of admission to hospital are shown separately. The three patients who arrived at Karachi only a short time before the onset of symptoms are not included.

FIG. 6.

and conduction depends on the difference between body temperature and air temperature (assuming no additional radiation factor). Thus a completely anhidrotic individual in still air at a temperature of 82 deg.F. may just be able to keep his body temperature normal. During the heat of the day a certain amount of extra heat may be stored in the body by a rise in skin and tissue temperature, but unless thermal equilibrium can be restored by losing this extra heat at night the body temperature will continue to rise and symptoms will occur. Thus in places where there is no marked rise in temperature during the day the onset of symptoms in acquired anhidrosis is likely to be correlated with the minimum dry bulb temperature, which determines non-evaporative heat loss at night.

This appeared to be true at Karachi in 1946 when the number of men developing symptoms severe enough to need admission to hospital increased rapidly during a period when the minimum air temperature did not fall below 86 deg.F., although the reduction in sweating had developed earlier (Figure 6). The figure also shows the effect of one cool night in stopping the "epidemic" of new cases.

When the daily temperature rises to levels well over 100 deg.F., as at Karachi and Cawnpore in 1947, it might be expected that the mid-day temperature would overtax the ability of the body to store heat and that symptoms would be related more nearly to the maximum than the minimum temperature. This appeared to be true at Karachi, where three of the four cases had their first symptoms at a time of exceptional maximum temperature. At Cawnpore, on the other hand, the onset of symptoms appeared /

appeared to be correlated more nearly with minimum than maximum temperatures.

It is less easy to discover which environmental factor was responsible for the failure of sweat production since it is not possible to be sure that the period immediately before the onset of the first symptoms was in fact the period during which the failure of sweat production originated. Sometimes case histories leave no doubt that the anhidrosis came on abruptly and was complete from the beginning. On the other hand, a precipitating incident was not always responsible for the anhidrosis since in other cases it is clear that the reduction in sweating was at first partial and only later became complete, a process actually observed in one individual in 1947. In such cases, did the cause of the complete anhidrosis antedate the time when partial failure was first observed or were the environmental conditions during the subsequent interval responsible for converting the partial reduction in sweating into a complete failure? This is a question impossible to answer, but the evidence on the whole suggests that the anhidrosis was caused by a continued, prolonged and unrelieved exposure to heat. This was first suggested by Ladell et al.(1944) who found at Shaiba that cases continued to occur for several weeks while environmental conditions slowly improved, and at Karachi also there was similarly suggestive evidence. One cool night appeared to stop an "epidemic" of cases in spite of a subsequent period of minimum temperature nearly as high as before, and there was a rapid increase in the number of cases in the last week in June 1946 without any /

any worsening in the environmental conditions. Also, the earlier the onset of symptoms the longer before recovery occurred. Experimental exposures to heat are normally intermittent and short and this may explain why no case of acquired anhidrosis ever seems to have been produced experimentally.

A factor as important as environmental temperature in deciding whether the body temperature will rise and when symptoms will occur is the rate of metabolic heat production. At Karachi in 1946 the highest incidence of cases of the syndrome was in a pioneer company whose activities included laying a pipe-line across the desert and stevedoring at the docks. The incidence in the Army was more than double that in the Royal Air Force when the climatic conditions were the same (Table V, page 147). In the anhidrotic, avoiding exertion minimises symptoms, and there is the same difficulty with physical exertion as with environment in distinguishing the causation of anhidrosis from the production of symptoms in the already anhidrotic. However, there is no evidence to suggest that the incidence of acquired anhidrosis in the pioneer company was the same as in other units and that the higher incidence of the syndrome was merely the result of increased physical exertion increasing the numbers of those with symptoms. It seems much more likely that exertion was actually a factor contributing to the causation of anhidrosis.

It is interesting that the 1946 series included only one cook in spite of the fact that cooks sweated continuously and profusely at work. This sweating was not associated with much physical activity as most of the /

the heavy work was done by Indians, and the relatively low incidence among cooks may be indirect evidence that muscular activity is really a factor in the causation of anhidrosis.

The low incidence among cooks may also indicate the relative unimportance of the volume of sweat secreted, and thus throw doubt on the suggestion (Ladell et al.1944) that fatigue of the sweat glands is the basis of anhidrosis. A high chloride concentration of the sweat has also been supposed to indicate sweat gland fatigue, but the evidence given elsewhere shows that a high sweat chloride is not pathognomic of the syndrome and can occur with sufficient sweating ability to make hard physical exercise enjoyable.

Any complete explanation of the anhidrosis must account for the persistence of sweating from palms, soles and axillae (the "emotional" areas) and for the remarkable sparing of the sweat glands of the face, and in some cases of the neck, which resulted in the most striking clinical feature of the syndrome - the profuse outpouring of sweat from the face when the rest of the body was quite dry. Differences in innervation between face and trunk seem an unlikely explanation and in any case the sweat gland lesion is peripheral. The sweat glands of the face differ from those of the body in the more alkaline sweat they produce, and in the higher temperature of the skin of the face (Burtenshaw,1945). As the facial glands usually exist in an environment with a higher temperature than the body sweat glands they may not be so adversely affected by the raised skin and body temperature which is an inevitable consequence of environmental /

environmental heat, especially during physical exertion. That a raised skin temperature may of itself decrease sweat production is suggested by the effect of completely enclosing the forearm in plaster. After three weeks the ability to sweat on exposure to heat was much reduced (Plate 9)

DIFFERENTIAL DIAGNOSIS.

The diagnosis of anhidrotic heat exhaustion and collapse depends primarily on a knowledge of its existence, but also on an appreciation that sweating need not be entirely absent, for the degree of reduction in sweating necessary to produce symptoms depends on particular environmental conditions. Cases of the syndrome may present during an attack or with milder complaints of exhaustion.

Anhidrotic heat collapse must be distinguished from heat syncope and from dehydration heat collapse. Clouding of consciousness and tachycardia may be present in all three. Extreme tachycardia and breathlessness are found only in anhidrotic heat collapse, however, and so is a marked rise in body temperature. The most striking diagnostic sign is likely to be the hot dry skin of the anhidrotic. In the early stages of a fever the skin of the trunk may be equally dry, but so may the face, whereas in anhidrotic heat collapse the face, in contrast with the body, almost always sweats profusely.

Heat stroke may or may not be a consequence of acquired anhidrosis, but a distinction from anhidrotic heat exhaustion in collapse may be needed /

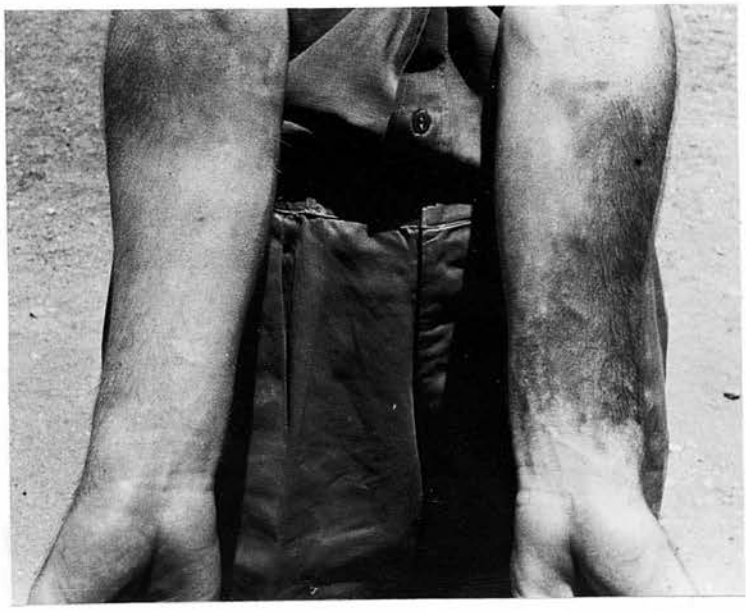


PLATE 9.

The effect on sweating of enclosing the forearm in plaster for 3 weeks. The right scaphoid was fractured 3 weeks before the photograph was taken, the plaster removed 3 days before. Both arms were dusted with gentian violet powder and the subject exposed to heat.

needed for prognostic and therapeutic reasons, although all gradations between the two may be seen.

Symptoms of exhaustion occur in salt deficiency, effort syndrome, psychoneurosis (including tropical neurasthenia), and in many other conditions. A careful history, especially of the time relationship of symptoms, sweating deficiency and heat stress, should clarify the diagnosis. Tests of sweating function may be helpful but their value is limited, as has already been stressed. The syndrome should not be diagnosed merely on the co-existence of mammillaria and reduced sweating.

The differential diagnosis of anhidrotic heat exhaustion and collapse may therefore present considerable difficulty, especially during an epidemic of heat effects, when other conditions must be distinguished from it. The following case history illustrates some of the difficulties in diagnosis that may be encountered.

Case history. A patient was sent into hospital as a case of anhidrotic heat exhaustion at a time when many of these cases were occurring because he gave a history of prickly heat which had cleared up recently in spite of the persistently unpleasant climatic conditions, of a stoppage of sweating, and of fever without abnormal physical signs. On the night before admission he complained of a headache. The following morning, on waking, he felt generally unwell and found that he was not sweating on any part of the body and that his temperature was 100 deg.F. He took a large quantity of salt and water and, although he said that he felt better after this, the skin remained hot and dry. He did not sweat all day and by the evening, when he reported sick, his oral temperature was 103 deg.F. He was given "ice baths", but the temperature was reduced only to 102 deg.F. and immediately rose again to 103 deg.F., in spite of the fact that the atmosphere was considerably cooler. During the day he had been passing urine every two hours. On admission to the hospital that night his oral temperature was 103 deg.F., pulse rate 90 per minute, and respiratory rate 20 per minute. He looked flushed and slightly anxious, but not ill. His skin was hot to the /

the touch, but slight sweating was present all over the body. Mildly active prickly heat was present in patches, but the skin elsewhere was normal. Blood films revealed no malarial parasites, and the total white blood count was 8000 per cu.mm. He was placed under a fan in the ward, but no vigorous steps were taken to reduce the temperature, and he was given a sedative.

His temperature gradually returned to normal over a period of a week. Anorexia and nausea became prominent symptoms, and on the ninth day after admission he was found to have clinical jaundice and the urine contained bile pigments.

This officer was sent for admission to hospital with a diagnosis of anhidrotic heat exhaustion, although in fact he was suffering from the invasive stage of infective hepatitis. His history illustrated some of the difficulties in the differential diagnosis. When prickly heat clears up in spite of the persistence of an adverse environment it does not necessarily mean that there has been a pathological reduction in sweating. The general symptoms were present on waking in the morning and there was cessation of sweating over the whole of the body. These are unusual in anhidrotic heat exhaustion, but are common at the onset of an acute febrile illness. Frequency of micturition may occur in any condition where there is reduction of sweating and maintenance of fluid intake. Artificial cooling had little effect in controlling the temperature whereas it was always effective in uncomplicated anhidrotic heat exhaustion.

IMPORTANCE /

IMPORTANCE OF THE SYNDROME.

During the summer of 1946, at Karachi, the only important heat effects syndrome among British Service personnel was anhidrotic heat exhaustion and collapse, and 1.1 per cent. of all other ranks who were at risk were affected. It was the commonest of the heat effects syndromes at Shaiba (Ladell et al.,1944) and apparently also in the American Desert (Wolkin et al.,1944). From the Service point of view the syndrome is important because of the waste of man-power it causes.

The immediate prognosis of the syndrome is favourable, and only one possible death (from secondary heat stroke) has been recorded, but there is a potential danger from hyperpyrexia. If local conditions are not suitable for early discharge and if there is difficulty in evacuating patients to a cooler area, prolonged hospitalization may be necessary, and may lead to deterioration of morale and possibly to effort syndrome and neurosis. The ultimate prognosis also seems favourable, and after recovery continuation of service overseas is not necessarily precluded.

If heat strain is the cause of the syndrome, the incidence may be relatively small under "peace-time" Service conditions. Reduced hours of work, avoidance of physical exertion in the heat of the day, and spells of leave in cooler areas during the hot season, will all help to prevent the occurrence of cases. A greater respect for severe prickly heat and early diagnosis of cases of the syndrome, and their removal from heat strain, even temporarily, should reduce the incidence of the syndrome.

It /

It is impossible to assess the importance of the syndrome amongst European civilians in the tropics as no such cases appear to have been recognised. The relative ease with which civilians may relax when feeling off colour, or may continue to attend to sedentary business at the cost of little physical exertion, probably protects them from the syndrome, just as they are protected as a rule from severe prickly heat. There is usually no necessity for civilians with minor symptoms to continue to expose themselves to heat strain, so that fully developed cases of the syndrome are not likely to occur.

Anhidrotic heat exhaustion and collapse seemed as novel a syndrome to Indian doctors as to British, and no Indian with the syndrome has been heard of. This may be due to the same factors that protect European civilians, but there may also be a racial protecting factor, as there is supposed to be against prickly heat.

There is no reason why this syndrome should not occur in temperate climates, although the acquired anhidrosis is then not likely to be caused by excessive environmental heat, and indeed it has already been described in cases of the rare type of congenital ectodermal dysplasia in which there are no sweat glands, and when anhidrosis has been acquired following conditions other than prickly heat. A study of the literature of the hitherto unexplained condition of "cerebral rheumatism", a dreaded complication of rheumatic fever before the introduction of salicylate therapy, when sweating was profuse and unrelieved for prolonged periods, suggests that many of the cases appear to have died from heat stroke following cessation of /

of sweating (Horne, to be published). The syndrome of anhidrotic heat exhaustion and collapse is also of considerable general interest because its symptomatology can be so completely explained in terms of known physiological responses.

SUMMARY AND CONCLUSIONS.

A detailed description is given of anhidrotic heat exhaustion and collapse, a heat effects syndrome seen at Karachi in 1946 and 1947. The syndrome was first described under other names in 1944 and has now been seen in Australasia, America and Asia. Ignorance of the existence of the syndrome has led to cases being missed or confused with other types of heat effects. In 1946 at Karachi there were fifty-eight cases (1.1 per cent. of those at risk), and a review of all the heat effects in the area showed that this syndrome was by far the most important.

There was an invariable sequence of events preceding the onset of symptoms. First, severe prickly heat, then an improvement in the prickly heat associated with a reduction in sweating and the development of a characteristic skin change, here called "mammillaria". The onset was sometimes gradual, with a wide variety of symptoms classifiable under the heading of "exhaustion". The body temperature was usually raised and often there was polyuria and frequency of micturition. Sometimes the onset was sudden, often as a direct result of exposure to heat or physical exertion /

exertion, with considerable distress, tachycardia and breathlessness, and even clouding of consciousness or collapse. The body temperature might then reach a hyperpyrexial level. The collapse and acute symptoms of such an attack were rapidly relieved by rest and cooling, and were succeeded by the milder exhaustion symptoms. In some cases the symptoms were never severe enough to interfere with work, and occasionally a spontaneous remission appeared to occur.

On examination the face was flushed and sweating. The skin and trunk showed mammillaria and the whole of the body was pale and dry except for the sites of emotional sweating. Loss of the ability to sweat was confirmed by observation after deliberate exposure to sweating stimuli such as heat, exertion, and the injection of carbachol. The evidence suggested that the anhidrosis was due to a peripheral failure of sweat secretion and not to failure of a central regulatory mechanism. The sweat chloride concentration and pH was considerably raised in all cases of the syndrome.

The duration of the anhidrosis varied from two weeks to three months, with an average of about six weeks. Recovery could be complete as judged by the ability of some cases to withstand a subsequent hot season without symptoms. The complications of the syndrome were hyperpyrexia and skin sepsis.

The onset of symptoms depended principally on the extent to which the subject with anhidrosis exerted himself and on the minimum air temperature, but it was not easy to distinguish the effect of environment in causing the anhidrosis from its effect in causing symptoms in an individual /

individual already anhidrotic. The cause of the anhidrosis seemed to be heat strain, a term which includes the combined effects of exposure to environmental heat and of increase in metabolic heat from physical exertion. Chloride deficiency did not seem to play any part in the syndrome.

It was possible for individuals to lose their ability to sweat, in whole or in part, without experiencing any symptoms, presumably because their requirements for heat loss were adequately met without the assistance of evaporation. In such individuals the return to full sweating seemed to be much quicker than in those who showed no symptoms.

There was clinical evidence that anhidrosis was responsible for the symptoms. These began at a variable period after sweating was reduced, never before, and recurred on exposure to heat while the deficiency in sweating persisted but not thereafter. Confirmatory evidence was provided by consideration of the similarity of the symptoms to those experienced by normal subjects exposed to environmental heat in circumstances which prevented evaporative cooling, and of their identity with those shown by individuals with congenital anhidrosis.

Anhidrotic heat exhaustion and collapse occurs in both humid and desert climates. Its pathological basis is sweating deficiency and its symptomatology the same whatever the climate, but the degree of sweating reduction necessary to cause symptoms is less in the hotter environment. This conclusion is based on personal experience at Karachi and on a comparison of the published accounts of the syndrome. Climate may modify the /

the clinical picture; for example mammillaria may not be visible in dry climates, but a detailed comparison of all the accounts showed that they were dealing with the same syndrome.

Evidence from Karachi, Cawnpore and Shaiba showed that the minimum dry bulb temperature was the main environmental factor determining the occurrence of the syndrome. At Karachi a minimum temperature of 84 to 86 deg.F., with a humidity of 80 per cent., was responsible for a sudden outbreak of 58 cases.

The differential diagnosis of the syndrome is discussed. Its recognition depends on a knowledge of its existence and of the difference in the clinical picture during and between attacks and in different climates.

The syndrome was much the most important of the effects of heat at Karachi and probably also in Australasia, and even in the desert at Shaiba it was as common as chloride deficiency.

CHAPTER 12.

MAMMILLARIA.

Clinical observations and discussion.

As already stated in chapter 11, this was the name suggested for the characteristic appearance of the skin in cases of anhidrotic heat exhaustion (Plates 10,11,12). The first descriptions of mammillaria were given in the accounts of this syndrome by Allen and O'Brien (1944) and Wolkin et al. (1944), neither of whom gave it a name. Allen and O'Brien (1944) and O'Brien (1947) realized that this skin change occurred apart from the syndrome, and their accounts will be discussed after the description of of the condition as it was seen at Karachi.

The affected skin is studded uniformly with pale firm elevations giving a "cobblestone" appearance. The closely packed elevations are roughly circular and more or less constant in size, about 1 mm. in diameter. They are more or less prominent depending on their height but on palpation always seem to lie "in" the skin as if they were due to alterations in the dermis. Several may lie within one polygonal area between the skin furrows, but they are always discrete, never confluent. They bear no constant relation to hair follicles or to the openings of the sweat ducts. They are pale and appear to contain less melanin and less blood than the surrounding skin. The affected skin feels rough like the studs of a nutmeg grater.

Mammillaria /

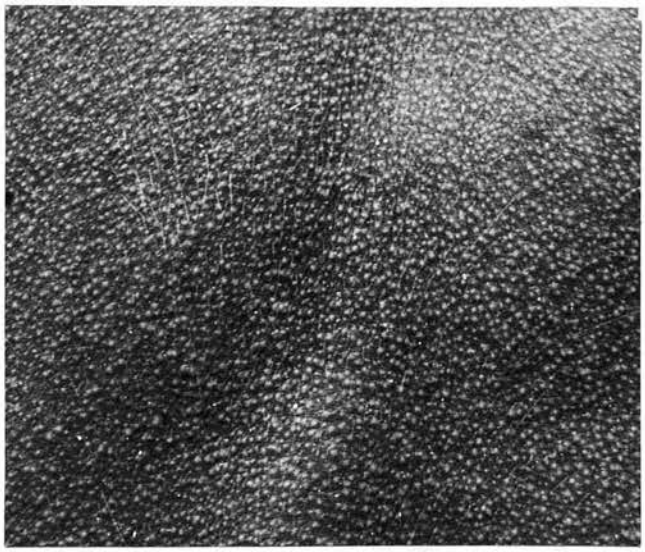


PLATE 10. Mammillaria in a subject with anhidrotic heat exhaustion with a tanned skin.

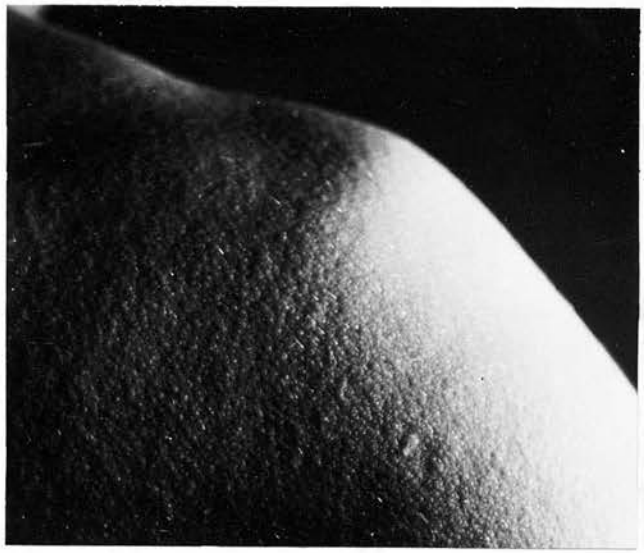


PLATE 11. Mammillaria on the shoulder photographed using oblique light.

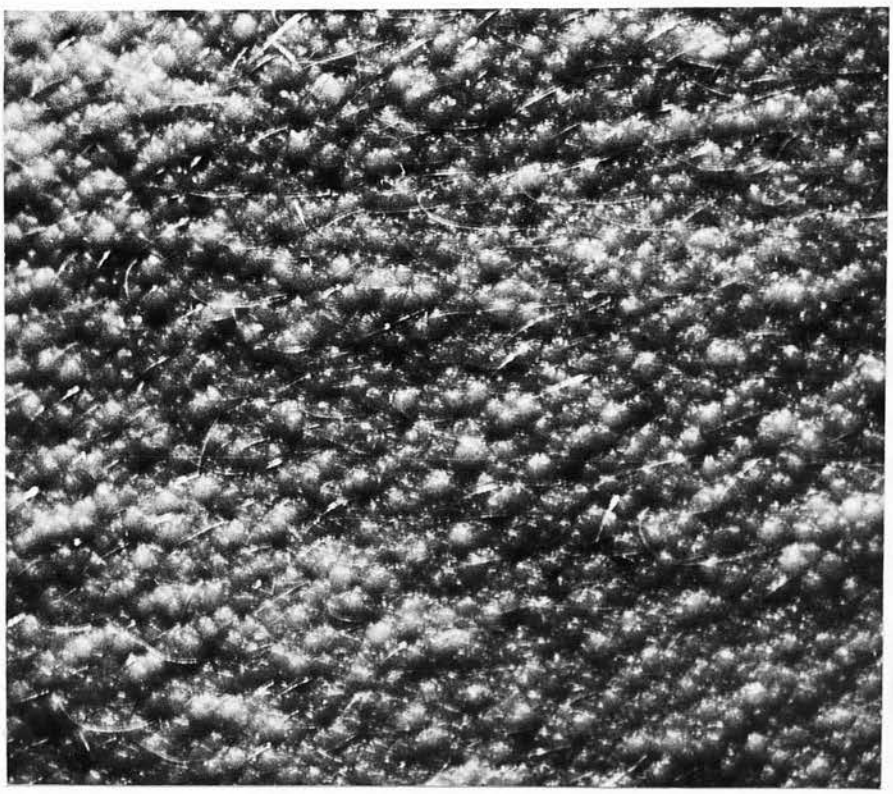


PLATE 12. Enlargement of lower central area of Plate 11.

Mammillaria is uniformly distributed from below the level of the neck over the anterior, posterior and lateral aspects of the trunk (but not in the axilla), as far down as the waist and over the lateral aspect of the upper arms as far down as the region of the insertion of the deltoid muscle. It is usually most prominent on the upper part of the thorax. Occasionally mammillaria is seen on the neck, but here the individual elevations are more widely spaced and run in parallel lines along the lines of cleavage with quite wide spaces between the rows of elevations (Plate 13).

The appearance of the skin varies very greatly according to whether the subject is at rest, and on how long it is since he was exposed to heat stress. The description given above applies to the resting individual but after exposure to heat or after physical exertion each lesion becomes much more prominent both to the eye and to palpation. However, there is no increase in the number of elevations per unit area of skin and usually the distribution over the body is unaltered. In extreme heat stress, however, mammillaria may extend down to the wrists, to the ankles and even on to the forehead. In contrast with the face, which flushes normally in response to heat or exertion, the affected skin remains pale but feels hot.

Mammillaria may persist for varying lengths of time, and the restoration of the skin to normal is a slow process. It has been seen to last for as long as 4 months, 3 of these in the temperate climate of Britain, but at Karachi it was never seen at the beginning of the following hot season. With the course of time it becomes less easy to recognise because /

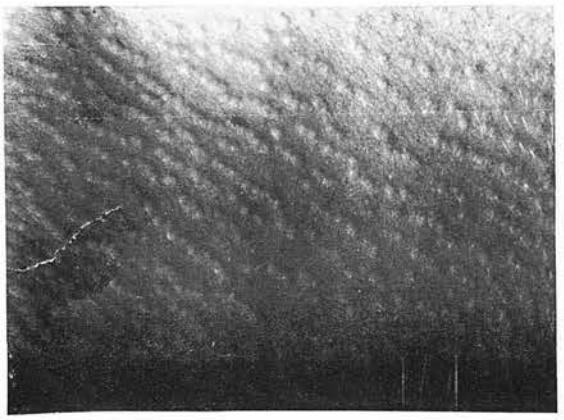


PLATE 13. Mammillaria on the neck.

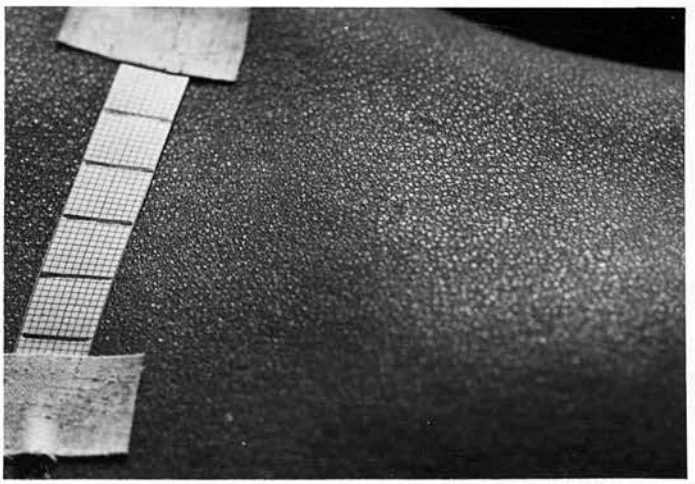


PLATE 14. Mammillaria in stage of regression.
(Scale in cm.)

because the elevations become flatter and are less influenced by exertion and exposure to heat. As the elevations flatten they also become less rounded and more polygonal, the shape being determined by the skin furrows which surround them (Plate 14). Adjacent elevations resolve at the same rate, so that restoration to normal is uniform, not patchy, although the shoulders and upper part of the thorax tend to retain the appearance longest.

As described above, mammillaria should be easy to recognise and in the light of its common occurrence it is surprising that the first clinical description should be as recent as 1944. Part of the difficulty is due to the way in which the lesions become less conspicuous as the individual rests and cools off. An oblique light may then be necessary and palpation is of little help. Difficulty also arises because prickly heat invariably precedes mammillaria and the drying and desquamating vesicles of healing prickly heat may conceal the underlying elevations.

At first sight the naked eye appearance of the skin may be likened to "gooseflesh". In gooseflesh, however, the hair follicles are found in the centres of the elevations, the changes are transient and the result of exposure to cold.

"Permanent gooseflesh" was the name given by Platt (1945) to a skin lesion associated with nutritional deficiency. His photograph, however, shows no resemblance to the condition described here. In the stage of regression when the elevations have flattened and become polygonal it is possible to confuse mammillaria with lichen planus.

The /

The above description is based on personal observation of a large number of men, and in most respects agrees with the accounts given by Allen and O'Brien (1944) and O'Brien (1947). These authors, however, stated that isolated patches of mammillaria were extremely common and that the patchily distributed lesions of prickly heat were seen individually to change into mammillaria. O'Brien (1947) also stated that the closeness with which the individual lesions were aggregated could vary with the degree of reduction in sweating. In both these respects their observations differed from that of the author.

Its evolution from prickly heat.

Mammillaria is an invariable feature of anhidrotic heat exhaustion in humid climates, and has even been considered diagnostic of the syndrome (Wolkin et al. 1944). Mammillaria, however, occurs much more commonly than anhidrosis and is usually symptomless. This was clearly demonstrated in 1946 at Karachi where on a day in July 38 per cent. of all members of the Hospital staff were found to have generalised mammillaria, as well as a wide variety of patients. Observation of a few healthy individuals with severe prickly heat showed that they developed mammillaria as their prickly heat cleared up, and in view of the invariable history of severe prickly heat preceding the mammillaria in cases of anhidrotic heat exhaustion an investigation was made in 1947 to determine the relation between the two types of skin lesion.

One /

One hundred and seventy men from three units with different ways of life and situated in different parts of the Karachi area were examined repeatedly by one observer over a period of 5 months. The majority of cases of prickly heat developed mammillaria as the prickly heat cleared up. The more severe the prickly heat the higher the incidence of mammillaria (Table VI). Those who failed to develop mammillaria were the mildest cases of prickly heat and a few persons with a very fair smooth type of skin, with shallow furrows and a tendency to freckles. Mammillaria was never seen without a history of preceding prickly heat.

TABLE VI.

The development of mammillaria in relation to the severity of prickly heat. (Hospital staff).

Severity of prickly heat	Number in group	Number who failed to develop mammillaria	Incidence of mammillaria (per cent.)
+	6	6	0
++	12	4	67
+++	14	3[x]	80
++++	6	0	100

[x] Two of these were of the fair-skinned type discussed in the text.

Prickly heat sometimes improved even when aggravating conditions such as environmental heat and physical exertion persisted or became worse. Mammillaria following such spontaneously healing prickly heat was usually more prominent than when it followed the improvement in prickly heat resulting from a lessening of the aggravating factors as in hospital or on /

on leave in the hills, or when the weather improved.

Mammillaria always had the same uniform and general distribution already described irrespective of the particular areas of skin which had shown the lesions of prickly heat, in contrast to what was observed by Allen and O'Brien (1944). When the skin had returned to normal it was again susceptible to prickly heat which might even recur while fading mammillaria was still present. It was possible to have mammillaria twice in the same hot season.

This description of the development of mammillaria from prickly heat is based on experience in a humid climate. In hotter and drier climates mammillaria may not occur. Ladell et al (1944) did not record it at Shaiba, and at Cawnpore, India, severe prickly heat was seen to clear up without the development of mammillaria (Floyer, 1947, personal communication).

Mammillaria in anhidrotic heat exhaustion.

The invariable occurrence of mammillaria in cases of anhidrotic heat exhaustion in humid climates and its frequent absence when this symptom occurs in hotter and drier climates has been emphasised in chapter 11. Both mammillaria and anhidrotic heat exhaustion appear to develop after severe prickly heat, and this common antecedent factor is probably responsible for the frequent co-existence of the two conditions. Further, after severe prickly heat mammillaria is prominent and with an increase in environmental heat will become more so. This may account for the close similarity /

similarity of the descriptions of mammillaria as seen in cases of anhidrotic heat exhaustion (Allen and O'Brien,1944; Wolkin et al.,1944; Sulzberger et al.,1946; O'Brien,1947). All agreed that here the change in the skin is uniform and generalised.

Mammillaria and sweating function.

The constant association of mammillaria and anhidrotic heat exhaustion has led to the belief that mammillaria is diagnostic of anhidrosis (Wolkin et al.,1944). Extensive experience of mammillaria at Karachi made it clear that this was not the case. Sweating over the areas of mammillaria was not necessarily absent although it was usually less than would be expected from the same areas of normal subjects exposed to the same heat stress, as could be confirmed by dusting with a gentian violet powder. This reduction in sweating was often associated with an increase of sweating above the normal on the face and on the buttocks and limbs, so that it was often possible to make a spot diagnosis of mammillaria in the clothed subject.

Subjects with mammillaria had a slightly higher skin temperature than normals, presumably because of the reduction in sweat volume. The pH of the sweat was slightly higher and the sweat chloride strikingly higher than normal.

O'Brien (1947) stated that it was possible to restore sweating on a dry area of mammillaria by the topical application of anhydrous lanoline, and gave a striking photograph in illustration of this "lipoid response". However, a similar result was obtained when the experiment was repeated in a temperate climate on a normal subject. The explanation seems to be that /

that the application of fat to the skin prevents the evaporation of sweat while visible sweat fails to appear on the rest of the skin because in a suitable environment the sweat is evaporated as fast as it is formed. The findings (O'Brien,1947) that the lipoid response varied with the kind of fat used, that the effect of the fat in mammillaria was only palliative and short-lived, that the lipoid response occurred in the majority of those with normal skins and did not occur invariably in all cases of mammillaria (some of which are truly anhidrotic), and that it was of little value in prickly heat (where sweating is known to be deficient), can all be explained on the basis that the local application of fat to the skin makes pre-existing sweating more obvious but does not increase the number of functioning sweat glands.

Symptomatology.

The only general symptom which appeared to be directly related to mammillaria was a feeling of warmth and "tenseness" or "fullness" under the skin following exertion or exposure to heat, as also noted by Allen and O'Brien (1944) and O'Brien (1947). This was quite different from the prickling and itching associated with active prickly heat, and subjects were often aware of the change in sensation when prickly heat cleared up and mammillaria developed. The main symptomatic significance of mammillaria is its association with reduction in sweating which, under certain circumstances, can lead to general symptoms.

Its /

Its anatomical basis.

O'Brien (Allen and O'Brien, 1944; O'Brien, 1947,1948,1950) has suggested that the elevations of mammillaria are subepidermal vesicles due to rupture of obstructed sweat ducts. Pricking the elevations with a pin was said to release a small drop of fluid, and skin sections were interpreted as showing obstruction of the sweat ducts. Sulzberger et al.(1946) accepted the suggestion on the same evidence which they confirmed in their own case, and the "sweat retention syndrome" has since been recognised in a number of other conditions (Sulzberger, Hermann and Zak,1947).

A wide experience of mammillaria at Karachi made it impossible to accept the suggestion that the elevations are fluid-containing vesicles. Fluid could not be obtained from characteristic elevations even when they were made as prominent as possible, and when fluid did appear it was always derived from a typical prickly heat vesicle which could co-exist with mammillaria in some circumstances. All degrees of sweating could occur in skin showing the same moderate degree of mammillaria, making it unlikely that the elevations were due to complete obstruction of sweat ducts. Further, when mammillaria was most intense and the skin anhidrotic, the elevations were more prominent but not more numerous or more closely packed together. Also when sweating and mammillaria co-existed the elevations could be seen to bear no constant relation to the openings of the sweat ducts, some lying between and some on the sides or summits of the elevations.

O'Brien (1947,1948,1950), Sulzberger et al. (1946), Shelley et al. (1950),Shelley (1951), all demonstrated that the lumen of each sweat duct was /

was occupied by keratin, and claimed that this keratin obstructed the sweat ducts and caused their rupture when sweat was secreted subsequently. Evidence was also provided (O'Brien, 1947) which suggested that local application of fat to the skin surface could cause the appearance of sweat on a previously anhidrotic area within half an hour of the application. This "lipoid response" was interpreted to mean that the fat had softened the keratin thus unblocking the sweat ducts; an alternative explanation has already been given. However, the lipoid response is given by normal subjects in a temperate climate so that, whatever its real explanation, the response is not due to a peculiar effect of a hot environment on the skin, and hence cannot be used as evidence for blockage of sweat ducts in mammillaria.

These observations suggest that there must be some other basis than obstruction of the sweat ducts. The rapid alterations in prominence of the elevations which could be produced in life, and the marked shrinkage of the elevations during histological fixation of biopsy specimens of skin, almost certainly mean that the elevations depend on the fluid content of the skin, but not necessarily in the way suggested by the observers mentioned above. Biopsy material obtained at Karachi in 1946 and 1947 has been carefully studied with a view to attempting to explain both the structural and other changes giving rise to the clinical condition of mammillaria and the nature of the disturbance of the sweat-secreting mechanism in anhidrotic heat exhaustion.

Histological /

Histological observations and discussion.

During 1946 and 1947 at Karachi biopsy material was obtained from subjects with normal skin, with prickly heat, with mammillaria, and with anhidrotic heat exhaustion. Local anaesthesia was used, 2 per cent. procaine (without adrenaline) being infiltrated in a "diamond" surrounding the area selected, and making sure that none of the solution reached the part that was to be removed. An elliptical piece of tissue, usually about ¾ to 1 inch long, about ¼ inch broad, and about ¼ inch deep, was removed and immediately placed in a fixative solution (Susa or formol-saline). In 1947, in the majority of cases, the skin was stretched to its original length and pinned to a piece of waxed cardboard before being placed in the fixative solution. This was done by marking the skin with silver nitrate before its removal, two spots being placed at a measured distance apart; after the skin was removed it was stretched until these two marks were restored to their original linear relationship.

Sections were stained with haematoxylin and eosin, by Van Gieson's method, by Fontana's method for melanin, by Weigart's and French's methods for elastic fibres, by Robb Smith's method for reticulin, and by a modified periodic acid-leuco-fuchsin technique.

Simple prickly heat.

Biopsies from subjects with sensations of prickling or with erythematous /

erythematous lesions only were not abnormal (Plates 15,16,17). In two subjects (both biopsies taken in June) there was an increase in perivascular cuffing by lymphocytes and histiocytes in the dermis. Cellular infiltration of this degree was also seen in control biopsies in normal subjects taken in the same month. This change may therefore have been a consequence of exposure to the climate of Karachi in May or June. On the other hand, all three controls had had prickly heat from which they had recovered, and this slight degree of cellular infiltration may therefore have some real association with prickly heat. At any rate its recurrence was not confined to <u>active</u> prickly heat.

<u>Prickly heat with vesicles</u>.

In subjects with clinically detectable superficial vesicles, vesicles were seen in the histological preparations. They were not seen histologically when they were absent clinically (Plates 18,19,20,21)[1]. The vesicles could appear to be in any level in the epidermis, depending partly on whether the section showed the centre or the periphery of the vesicle. The contents of the vesicles varied: sometimes the fluid was clear, sometimes contained protein, sometimes principally polymorphonuclear leucocytes which were mostly necrotic. Micro-organisms were not seen.

Serial sections did not convincingly show communications between a vesicle and a sweat duct. On the other hand, they suggested that the origin of the vesicles could be in a break in the continuity of the basal layers of the epidermis, with subsequent seepage of tissue fluid, with or without /

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[1] Vesicles were also seen in two subjects with anhidrotic heat exhaustion in whom sweating had returned.

PLATE 15. Low-power view of skin from a subject with prickly heat in the erythematous stage without vesicles (back). Skin stretched only slightly before fixation.

(Haematoxylin and eosin. X 30)

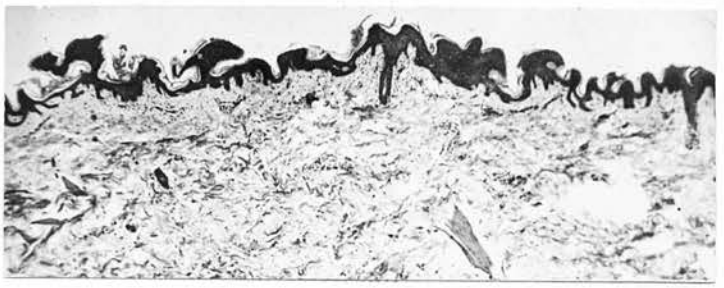


PLATE 16. Low-power view of skin from a subject with prickly heat in the erythematous stage without vesicles (forearm). Skin stretched to original length before fixation.

(Haematoxylin and eosin. X 70)

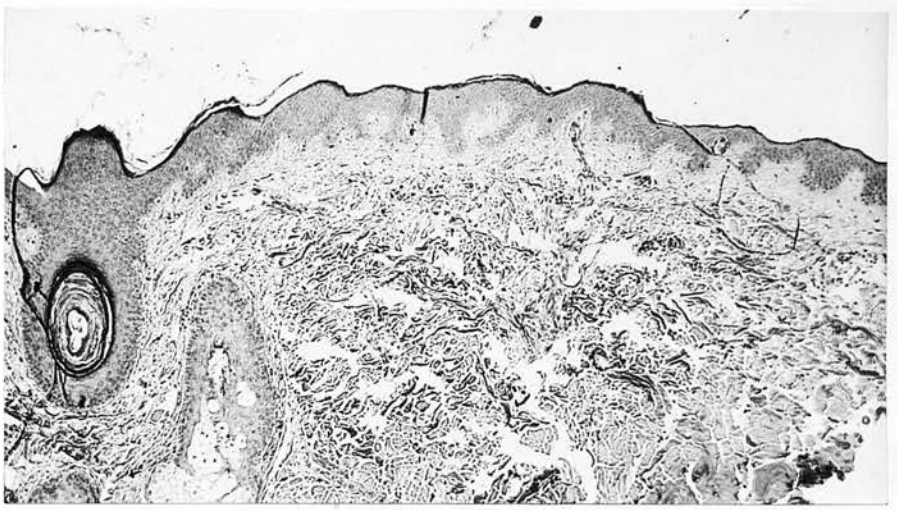
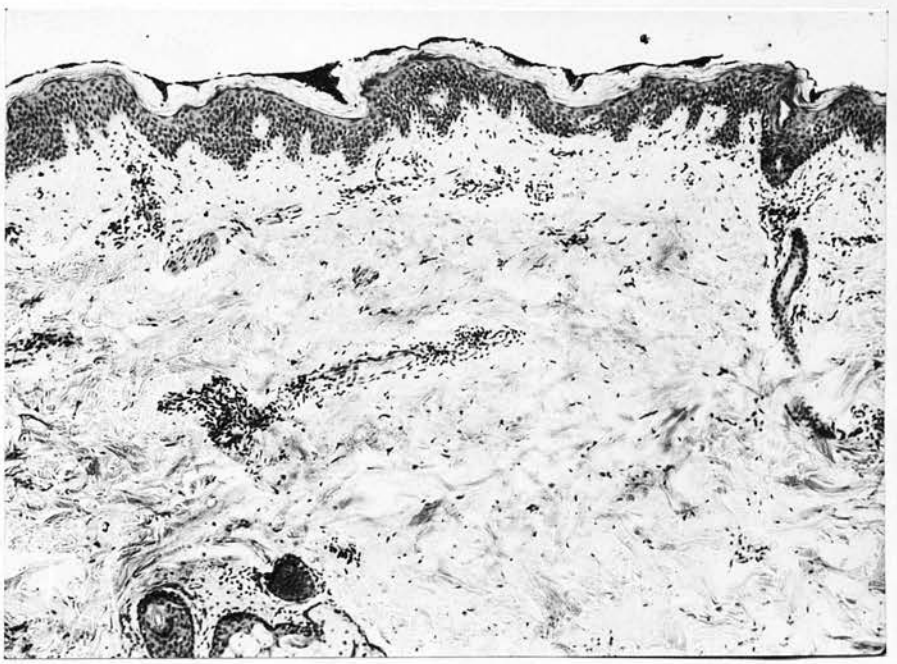


PLATE 17. Low-power view of skin from a subject with prickly heat in the vesicular stage, showing area without any vesicle (over scapula).

(Haematoxylin and eosin. X 70)



There is some increase in the thickness of the keratin layer; a small degree of cellular infiltration around the vessels in the papillary dermis, and a more intense area of infiltration with oedema in a deeper vessel. An obstructed sweat duct is visible at the right hand border.

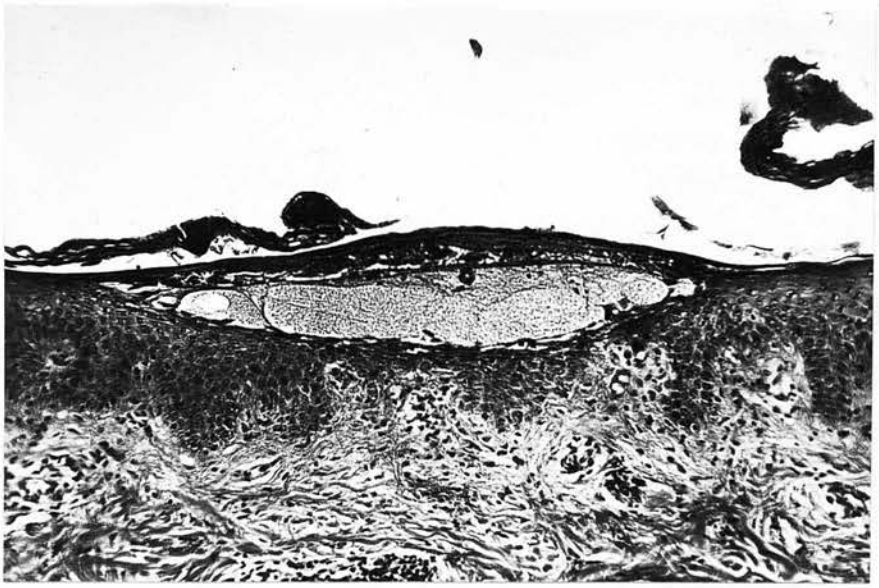


PLATE 18.

A more deeply placed vesicle (containing red cells) in vesicular prickly heat.

(Haematoxylin and eosin. X 110).

The roof consists of keratin with fibrin on its inner surface. The floor may not be quite complete at a point near the right hand end of the vesicle.

PLATE 19.

Superficial vesicle in vesicular prickly heat.

(Haematoxylin and eosin. X 160)

There are a few necrotic cells within the vesicle, probably polymorphonuclear leucocytes. The epidermis deep to the vesicle is disorganised.

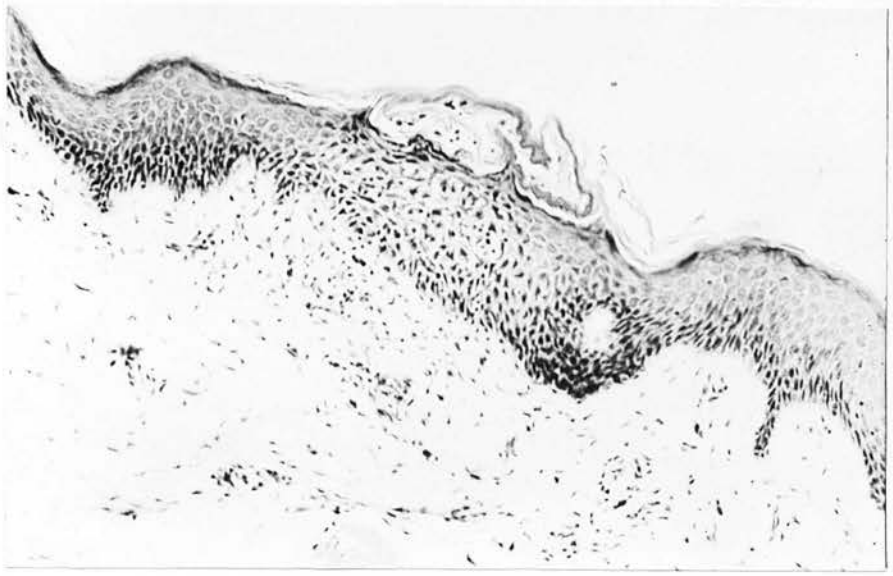


PLATE 20.

Superficial vesicle in vesicular prickly heat.

(Haematoxylin and eosin. X 70)

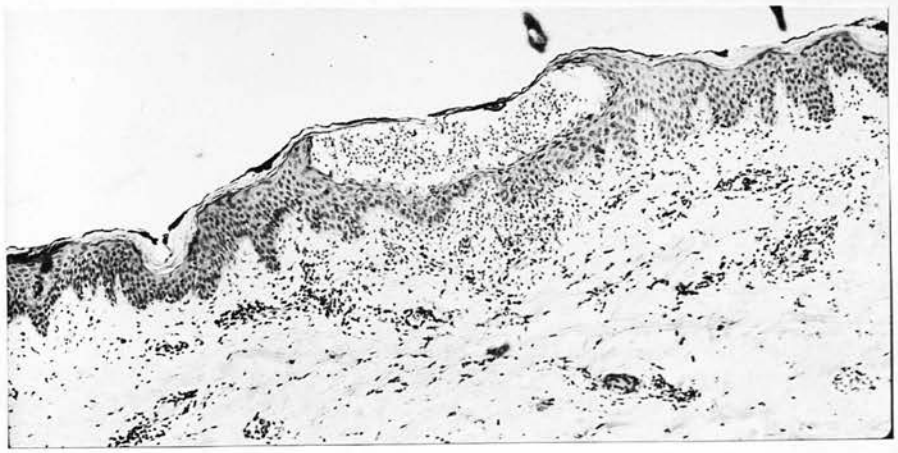
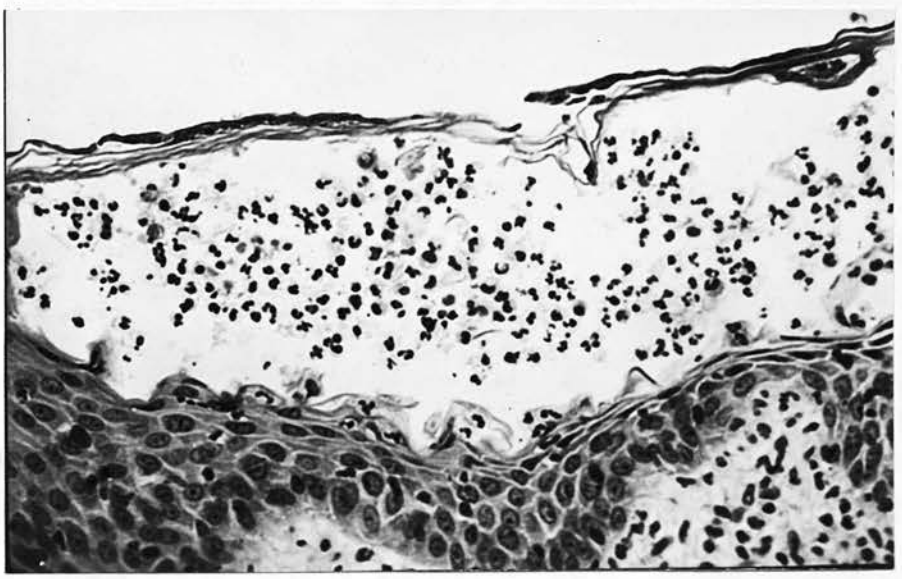


PLATE 21.

Magnified view of the central area of Plate 20.

(Haematoxylin and eosin. X 320)

The vesicle roof is keratin, the floor Malpighian cells or granulosa cells, in one place only three cells thick. The cells in the vesicle are mostly polymorphonuclear leucocytes. The rete pegs are diminished in size below the vesicle, and there is some oedema and perivascular infiltration in the adjacent part of the papillary dermis.



without plasma and blood, into the epidermis from below (Plates 22,23,24). The epidermis break could be minute but on the other hand in some places the loss of epidermal covering was quite extensive. Sometimes the loss of epidermis occurred near the opening of a sweat duct (Plates 25,26). The change in staining properties of the dermal ground substance immediately around the break is detectable in the photographs. It is uncertain whether this was a consequence of the break or bore some causal relation to it, but probably the former is the correct interpretation.

Direct observation of small vesicular papules in a case of prickly heat in this country showed that the vesicle contents were more alkaline than adjacent sweat droplets, that the fluid which exuded from the vesicle after it was broken open was similarly alkaline, and that when the flow stopped the fluid coagulated to form a kind of scab. These observations would all agree with the suggestion made here, but do not agree with the hypothesis that the vesicle is formed after rupture of a sweat duct and contains sweat, an acid protein-free fluid.

The "keratin ring" described by O'Brien and others at the mouth of a sweat duct was seen sometimes but not regularly. There was never any convincing appearance of obstruction of the duct. At the mouths of some ducts there was a cellular plaque usually within the keratin layer (Plate 27). This plaque was variable in structure but the impression was gained that fibrin, originally present in a vesicle or in an epidermal break, gradually condensed into a thin layer as it aged till finally the appearance was merely that of darkly staining and perhaps abnormal keratin.

Mammillaria /

PLATE 22.

Break in epidermis with overlying vesicle.

(Periodic acid leucofuchsin and haematoxylin. X 390)

The altered ground substance is seen to the right of the break below the basal epidermal layer.

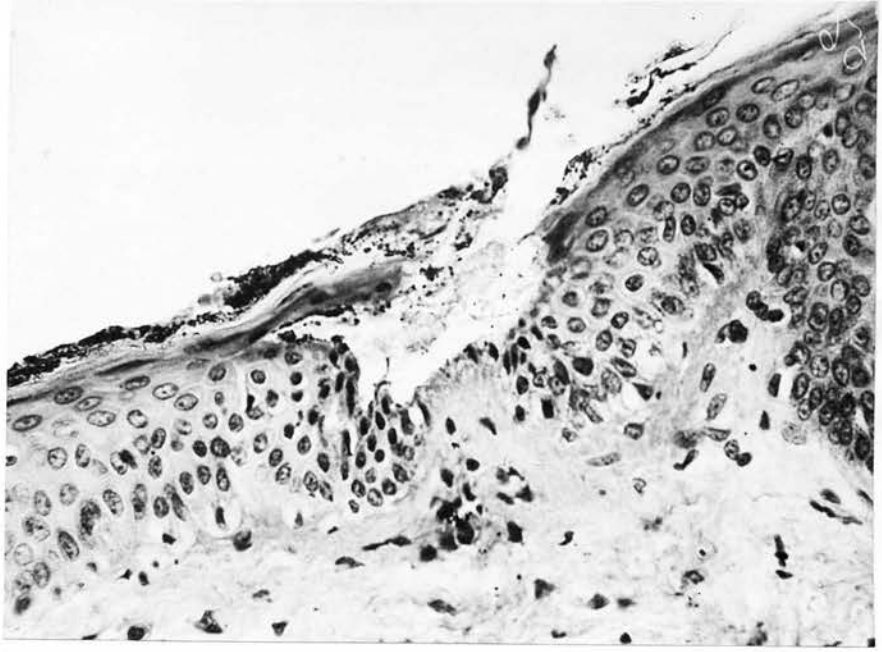


PLATE 23.

Break in epidermis with overlying vesicle.

(Periodic acid leucofuchsin and haematoxylin. X 390)

The altered ground substance is seen to both sides of the break and in the material filling the break.

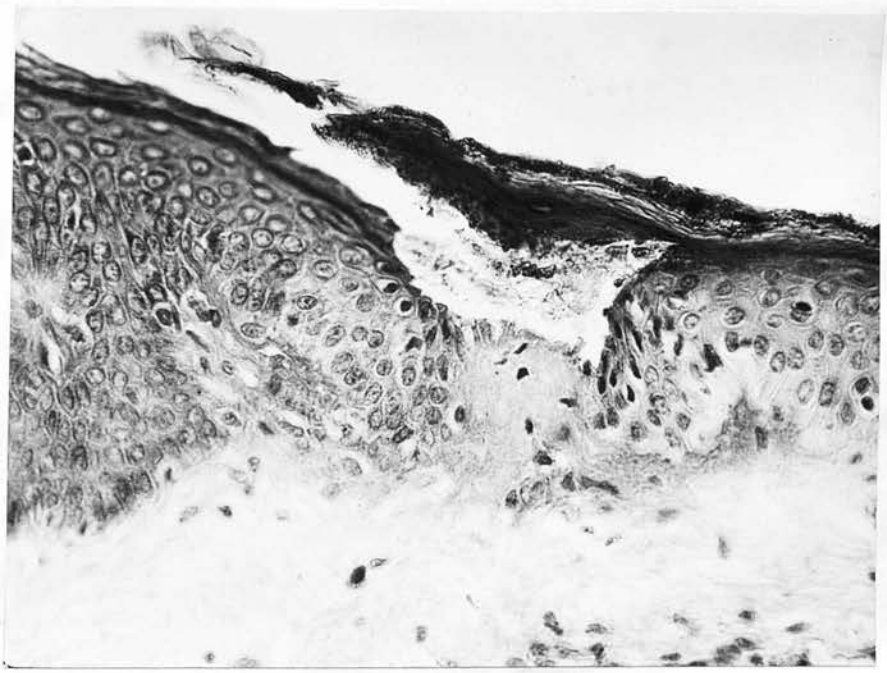


PLATE 24.

Break in epidermis with overlying vesicle.

(Periodic acid leucofuchsin and haematoxylin. X 390)

The section is nearer the edge of the vesicle which here contains some red cells. The roof of the vesicle contains cells from the stratum spinosum. Two capillaries are running up to the break which again appears sealed by altered ground substance.

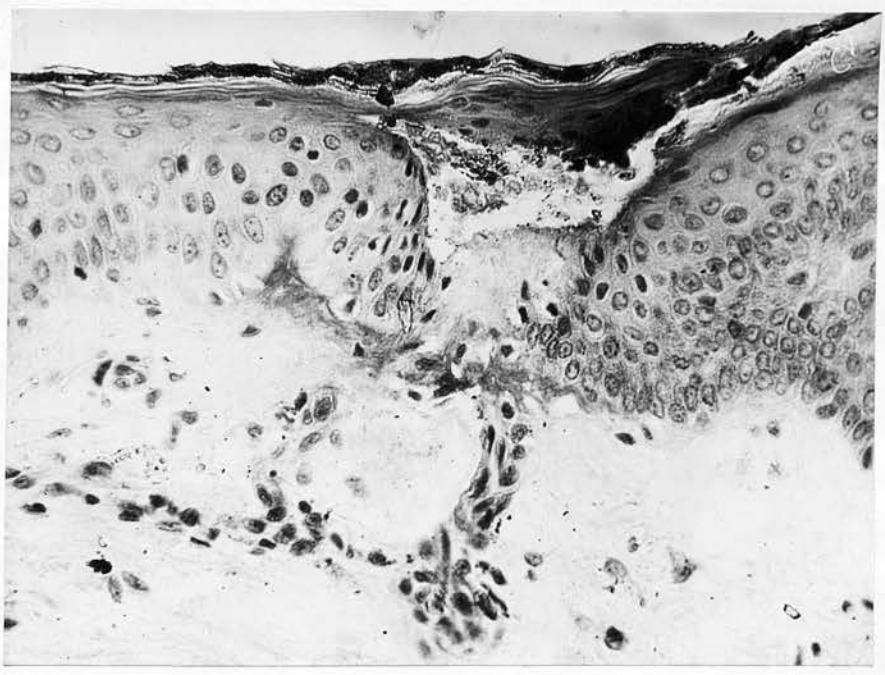


PLATE 22.

Break in epidermis with overlying vesicle.

(Periodic acid leucofuchsin and haematoxylin. X 390)

The altered ground substance is seen to the right of the break below the basal epidermal layer.

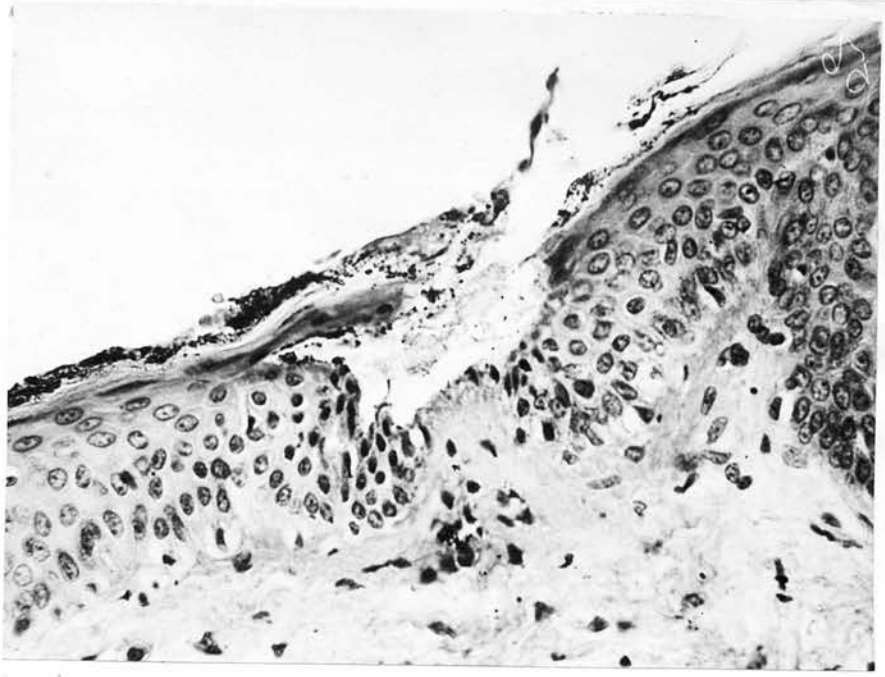


PLATE 23.

Break in epidermis with overlying vesicle.

(Periodic acid leucofuchsin and haematoxylin. X 390)

The altered ground substance is seen to both sides of the break and in the material filling the break.

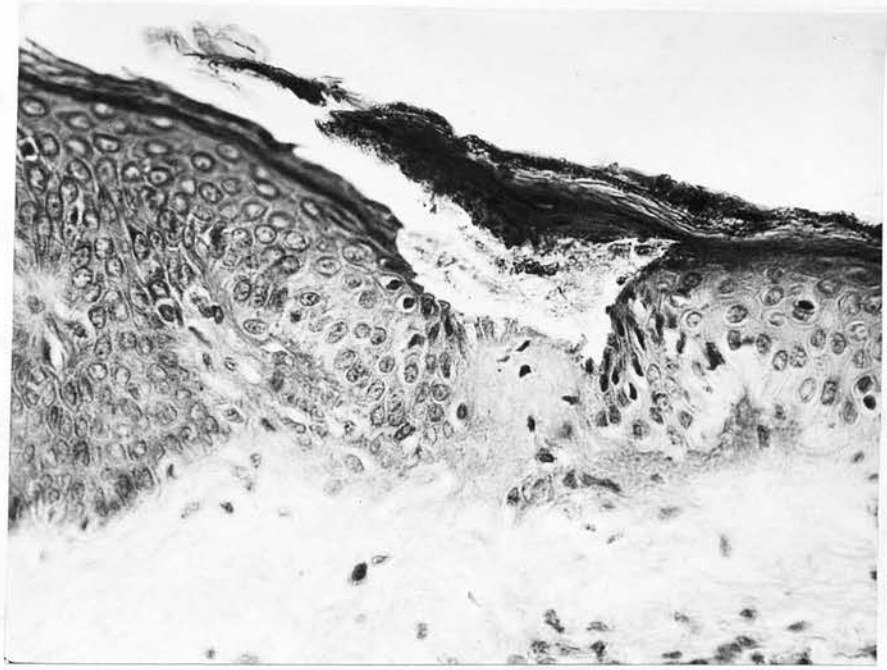


PLATE 24.

Break in epidermis with overlying vesicle.

(Periodic acid leucofuchsin and haematoxylin. X 390)

The section is nearer the edge of the vesicle which here contains some red cells. The roof of the vesicle contains cells from the stratum spinosum. Two capillaries are running up to the break which again appears sealed by altered ground substance.

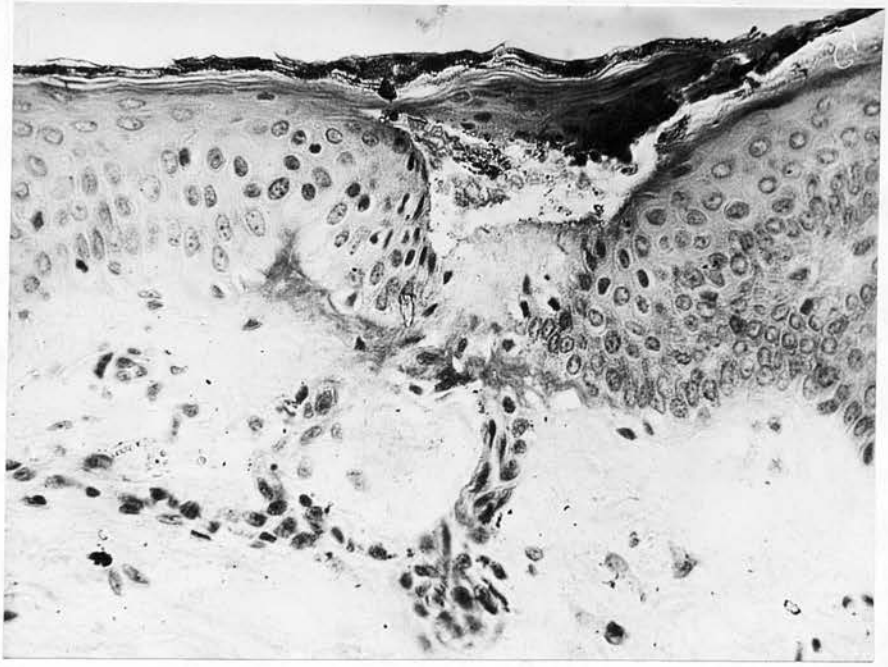
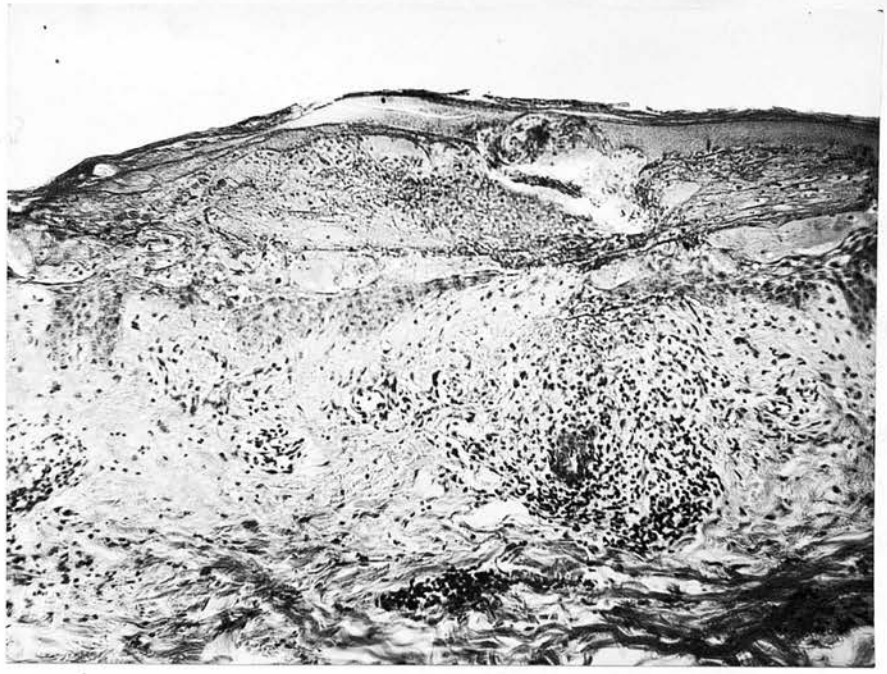


PLATE 25.

Break in epidermis with large vesicle.

(Haematoxylin and eosin. X 110)



The appearances suggest several successive leaks of blood with partial repair on each occasion. The contents of the vesicle include necrotic polymorphonuclear leucocytes and red cells. The epidermis is regenerating under the vesicle. A sweat duct below the vesicle is surrounded by an oedematous space infiltrated with polymorphs. (The dark circular area in the centre of the field near the surface of the vesicle is not the mouth of the duct).

PLATE 26.

Break in epidermis near to mouth of a hair follicle.

(Haematoxylin and eosin. X 30)

The vessel is filled with polymorphonuclear leucocytes which form the black mass in the superficial part of the vesicle. The epidermal break is plugged with fibrin and red cells. The dermis underlying the vesicle contains several congested blood vessels surrounded by oedematous spaces filled with cells. These do not show clearly in the photomicrograph.

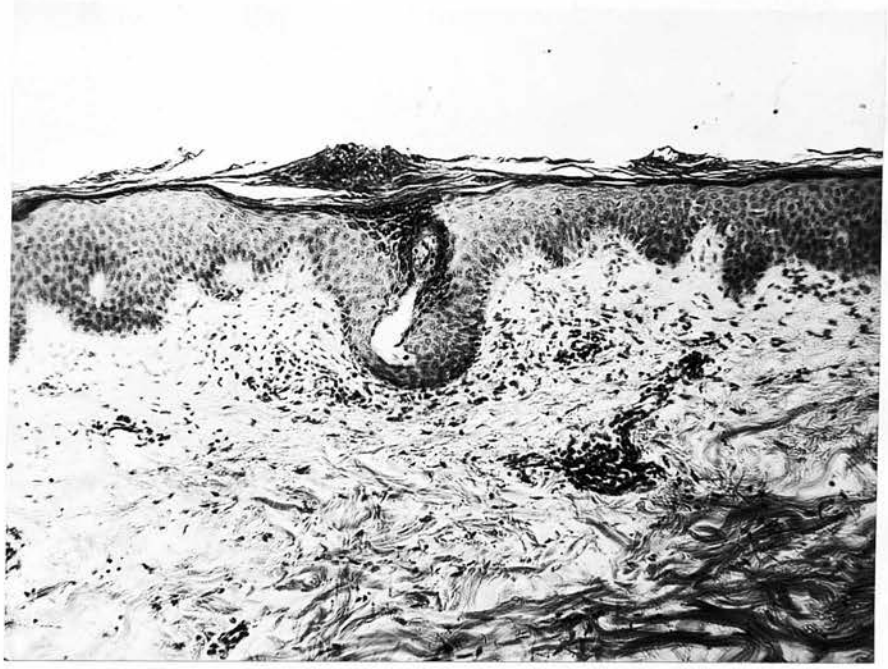


PLATE 27.

Fibrin plaque at mouth of sweat duct.
(Haematoxylin and eosin. X 110)
Above the sweat duct is a cellular mass which is formed of old condensed fibrin and longtitudinally flattened cells.

Mammillaria.

The clinical appearance of marked mammillaria is so distinctive that the absence of any obviously corresponding structure in biopsy material was unexpected. Focal lesions were present in the papillary dermis and will be described later, but it is not necessarily correct to assume that they correspond to the clinically visible elevations of the skin.

The features of mammillaria which might be recognisable histologically are the elevation of the epidermis above the surrounding skin grooves and the central pallor of the elevation in a suntanned subject. In an attempt to assist the correlation of the clinical and histological appearances some of the elevations were touched with silver nitrate solution about half an hour before the biopsy was made. Light reduces the silver nitrate to silver oxide and it was hoped that this would remain on the skin and be recognisable in the sections. In 1946 the skin sections were thrown into folds about 1 mm. across, as might have been expected. The skin sections from the 1947 cases, however, failed to show such regularly spaced elevations of the skin which could have been taken to correspond with those of mammillaria. Another difference between the two series of biopsies was that in 1947 the pieces of skin were stretched to their original length before fixation; in 1946 the stretching was much less. It seems unsatisfactory to conclude that mammillaria could have been obliterated by stretching.

In the 1946 series the position of the grooves between the elevations did not seem to be determined by any special arrangement of collagen, elastic /

elastic fibres or muscle.

Melanin staining showed that in normal skin and prickly heat, melanogen granules were absent from the basal epidermal layer only along the deeper parts of the sweat ducts. In some sections of mammillaria it was clear that there were stretches of epidermis up to half a millimetre long where the basal layer contained no black-stained granules. (Not all subjects with mammillaria show clinically a difference in brown pigmentation between the centre of the elevations and the normal skin between the elevations. Colour differences in the living subject also depended on vascularity.) In these regions the rete pegs were small and rounded or almost absent. Sometimes, but not always, a sweat duct approached the epidermis in or near one of these melanin-free zones. In the dermis below these zones there was always an area of oedema infiltrated with cells.

The silver oxide patch appeared as expected on the external surface of the epidermis (Plate 28). But no structure seemed to be regularly placed underneath the silver, until it was realised that the deeper vessels in the papillary layer were often surrounded by an oedamatous space filled with lymphocytes and histiocytes (Plates 29,30,31,32). These spaces were much more prominent and more easily photographed in sections stained by the van Gieson's method. In 1946 the spaces were roughly circular and up to $\frac{1}{2}$ mm. in diameter. In 1947 the spaces were elongated parallel to the skin surface, presumably due to the stretching the specimens underwent before fixation and the contraction of the connective tissue which occurred during fixation.

The /

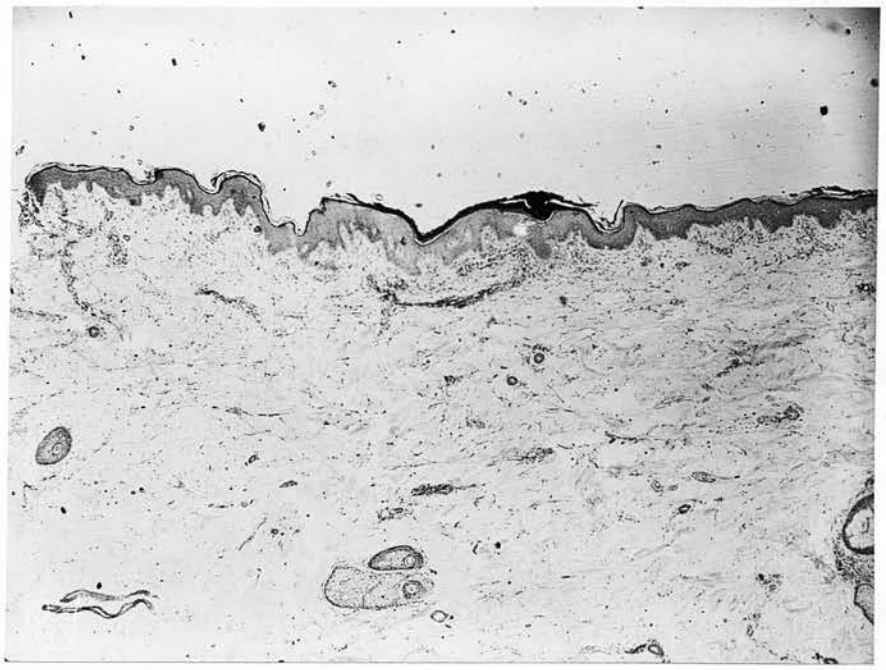


PLATE 28.

Silver deposit on mammillaria elevation.

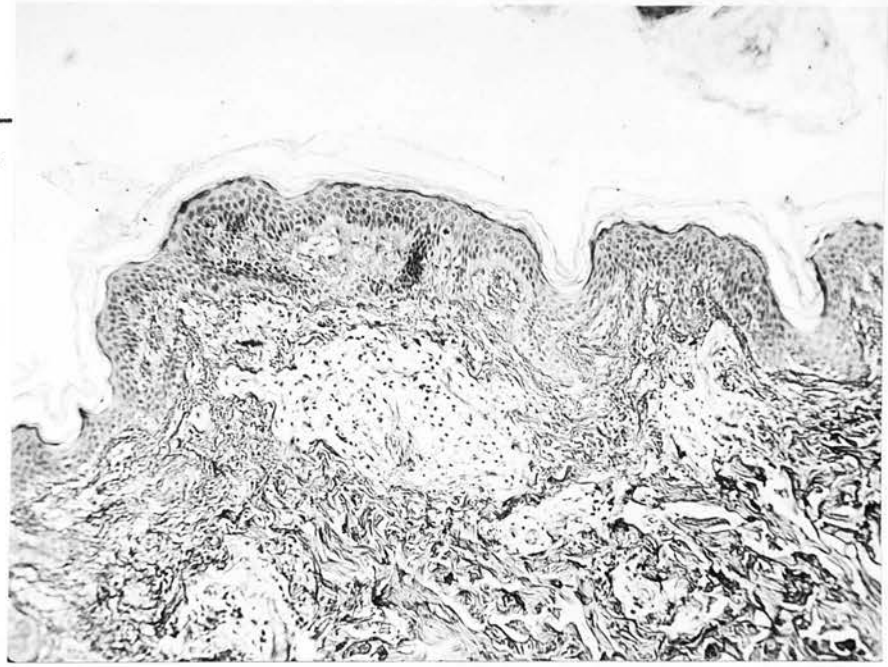
(Haematoxylin and eosin. X 30)

The dense black superficial material is silver oxide formed *in situ* before the biopsy was made. Instead of lying above an elevation of the skin, the silver deposit appears to be over a depression. This illustrates the difficulty in correlating histological and clinical appearances, and suggests that some fluid-containing space must have contracted during fixation. The paler staining of the epidermis below the silver is due partly to a loss of melanin granules in the basal layer, but principally to an alteration in the cellular density of the epidermis.

PLATE 29.

The histological counterpart of mammillaria from a piece of skin which was only slightly stretched before fixation.

(Van Gieson. X 110)

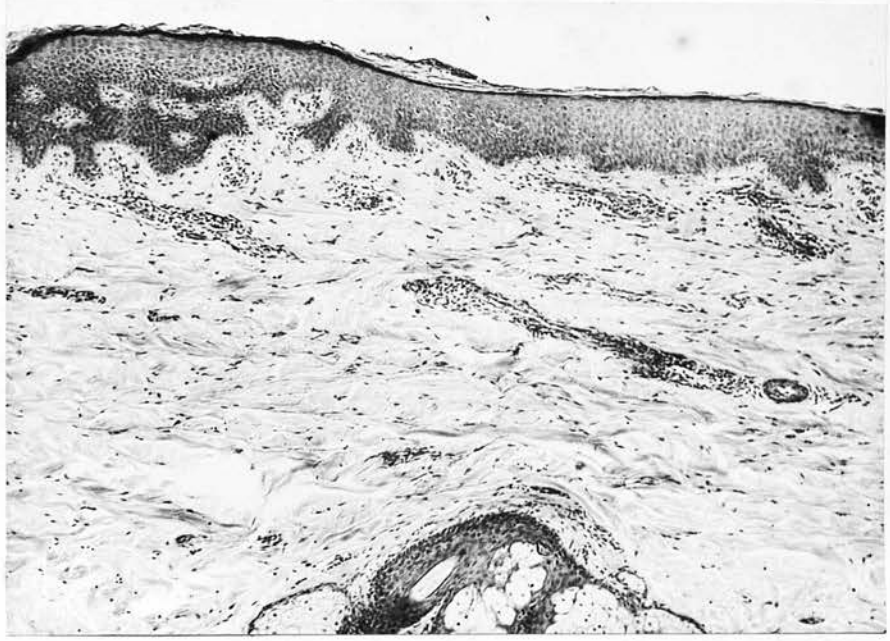


The oedematous spaces in the papillary layer of the dermis are very obvious. The largest measures 0.4 mm. along its long diameter, and the lesion is therefore of the right order of size.

PLATE 30.

Section of mammillaria skin which was stretched to its original length before fixation.

(Haematoxylin and eosin. X 70)

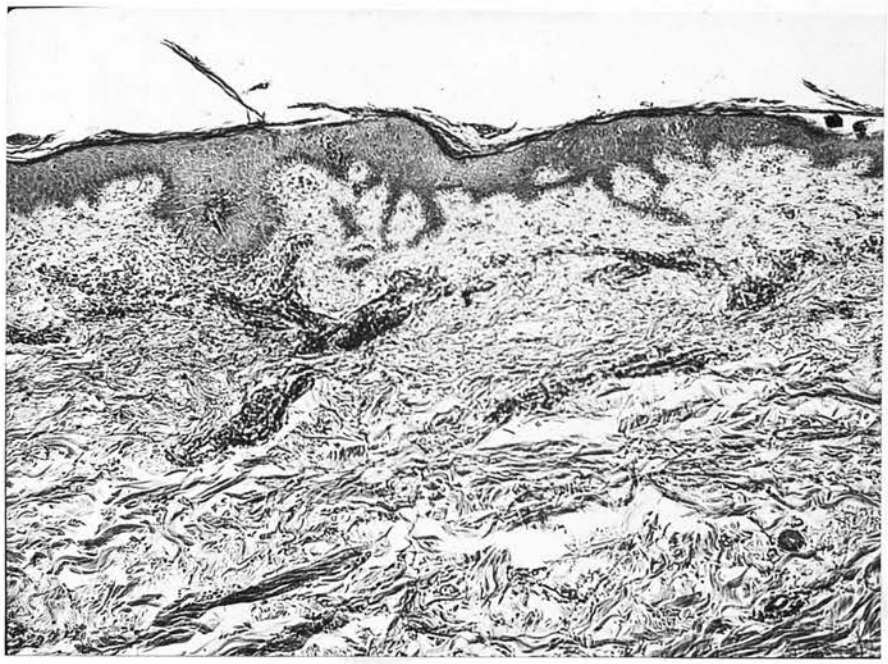


The tensions occurring during fixation seem to have twisted the specimen. On the left hand side the section is not parallel to the original surface, although on the right hand side it is. This phenomenon was frequently observed in the mammillaria biopsies. The perivascular spaces lie parallel with the skin surface and have been compressed in a direction perpendicular to the skin surface by the contraction of the specimen during fixation.

PLATE 31.

Section of mammillaria skin which was stretched to its original length before fixation.

(Haematoxylin and eosin. X 70)

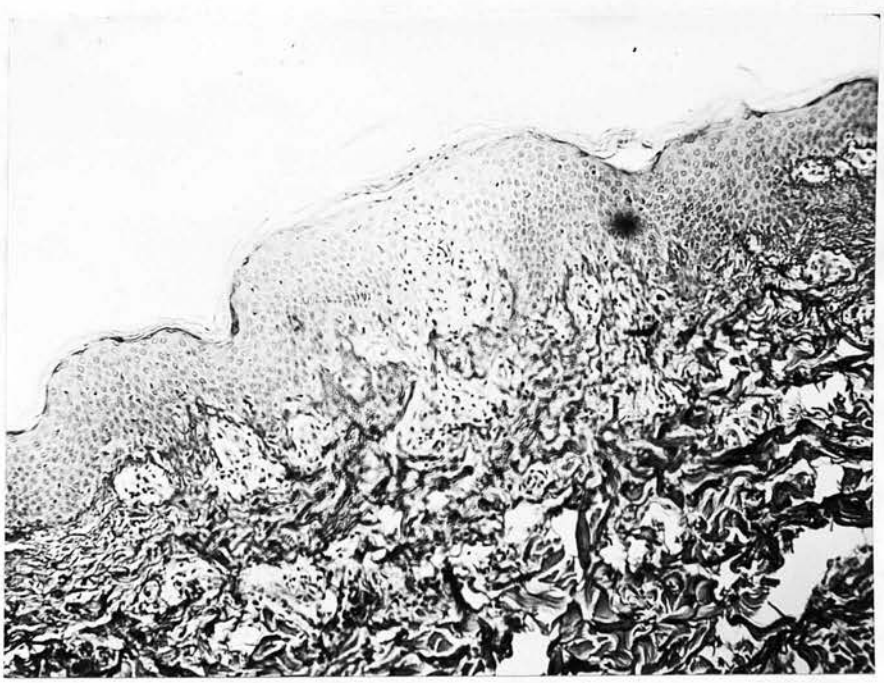


The appearances are similar to those in Plate 30, but are less clear cut.

PLATE 32.

Section of mammillaria skin which was only slightly stretched before fixation.

(Van Gieson X 110)



The appearances are similar to those in Plate 29, but the oedematous spaces seem to be stretching the epidermis, the cells of which seem to be pulled apart at the place where the base of the epidermis is separated by fluid from the collagen fibres of the papillary dermis.

The oedematous perivascular spaces were often continuous with oedematous spaces around the sweat ducts in the papillary layer of the dermis (Plates 33,34). Such lesions have been described by O'Brien, who called them the "anhidrotic vesicle" and considered them the anatomical basis of mammillaria. These areas are in themselves, however, too small to correspond with mammillarial elevations themselves. O'Brien also believed that the spaces were filled with sweat and were caused by a rupture of the sweat duct which passes through them. In some of the sections from the material obtained at Karachi it is true that the wall of the duct was badly disorganised just in this region, but there were other places where serial sections failed to reveal any defect in the sweat duct at all (Plate 35). A rupture of the duct cannot therefore be considered the cause of the fluid-containing spaces.

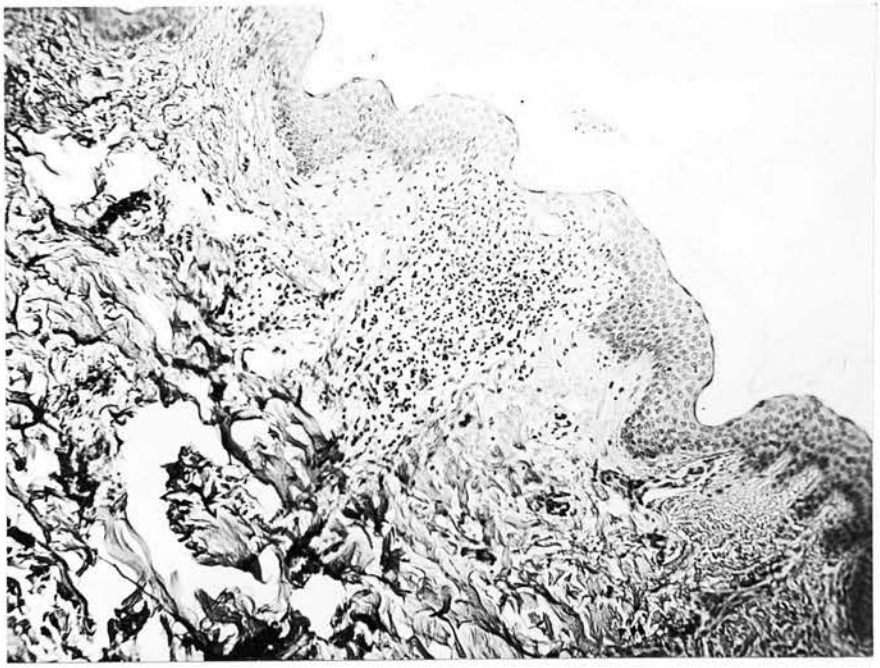
The cells which filled the oedematous spaces were mostly "round cells", lymphocytes and histiocytes (Plates 36,37). This histiocytic feature was beautifully demonstrated in several subjects by their aggregation into multinucleate cells. No specific cause for the formation of these giant cells was detected.

The large areas of oedema found in the papillary layer of the dermis are believed to be the anatomical counterpart of the clinical condition. The oedema fluid is thought to lift the overlying epidermis and to thin it out producing the visible elevations labelled mammillaria which is bounded by the more firmly anchored regions of the skin grooves. The lesion is independent of a lesion of the sweat secreting apparatus, thus agreeing with /

PLATE 33.

Oedematous space around a sweat duct (anhidrotic heat exhaustion).

(Haematoxylin and eosin. X 110)

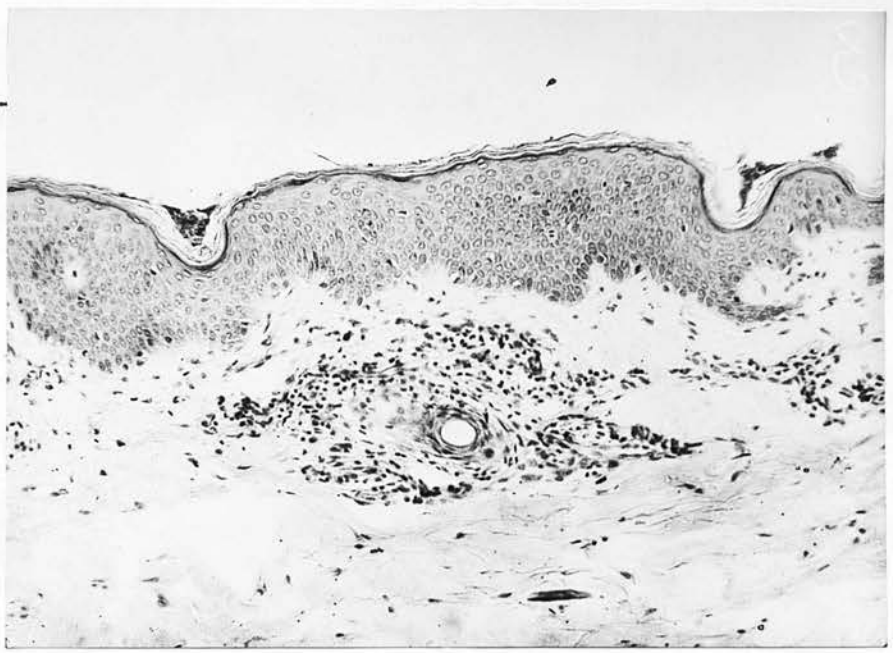


The duct is seen in transverse section at the level of the epidermis. The longtitudinal part of the duct is out of the plane of the section. (This is the periphery of a lesion of the type called by O'Brien the "anhidrotic vesicle" and believed by him to be due to rupture of a sweat duct and leakage of sweat).

PLATE 34.

Transverse section of a lesion similar to that in Plate 33, but less marked, from a subject with prickly heat.

(Haematoxylin and eosin. X 160)



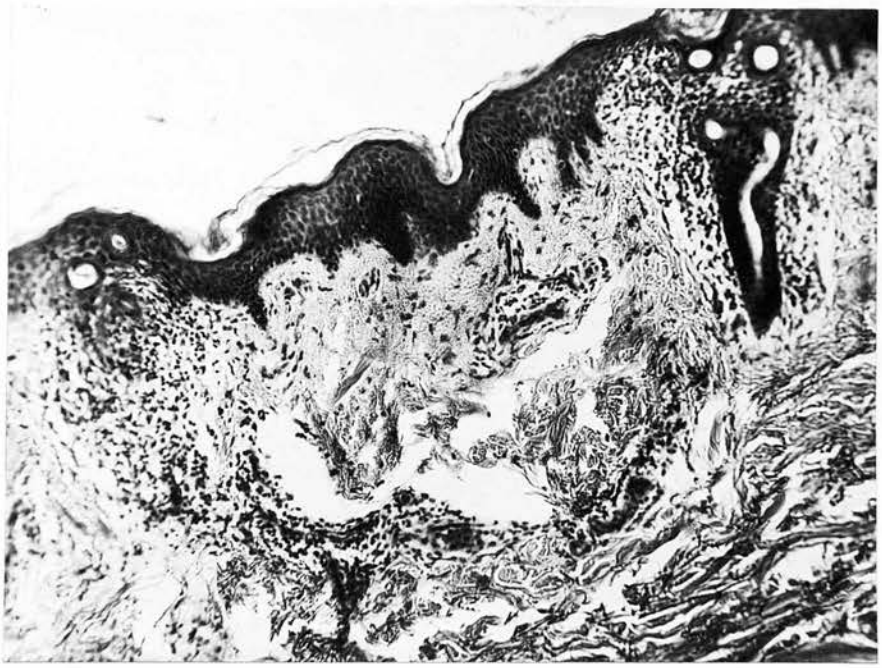


PLATE 35.

Two areas of periductal oedema connected in the papillary dermis by a perivascular space (anhidrotic heat exhaustion).

(Haematoxylin and eosin. X 110)

The central spaces are artefacts due to tearing of the section. Both sweat ducts have been seen in several sections in their entire course through the papillary dermis and epidermis. At no points were the ducts obstructed, or was there any loss of integrity of the duct walls. The periductal spaces are continuous with the perivascular spaces, and are believed to be direct extensions of oedema fluid along tissue planes of weakened resistance.

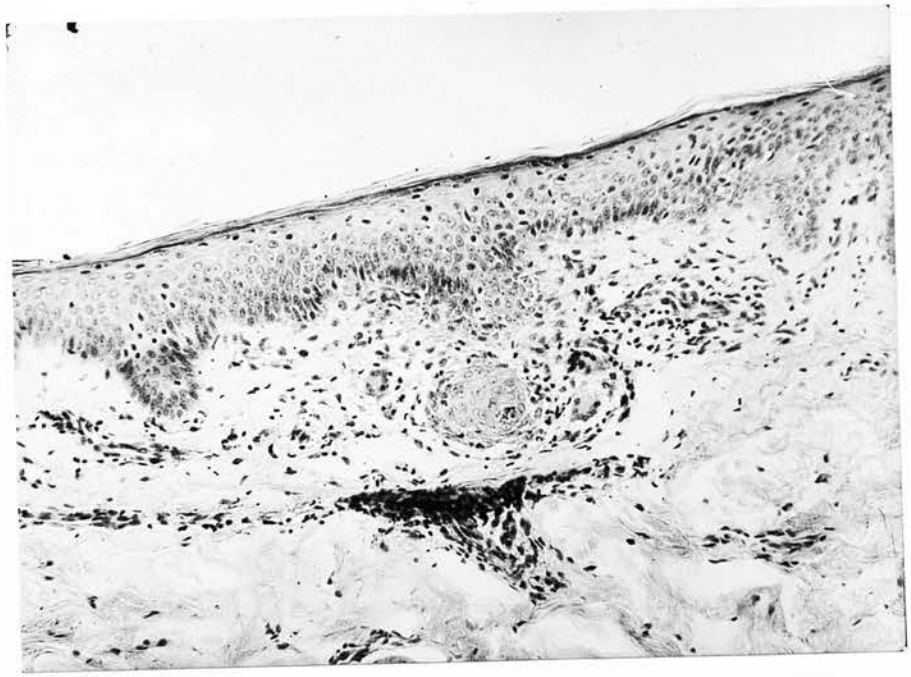


PLATE 36.

A giant cell focus around a sweat duct in a subject with prickly heat.

(Haematoxylin and eosin. X 160)

There are numerous lymphocytes scattered within the epidermis. their significance is unknown.

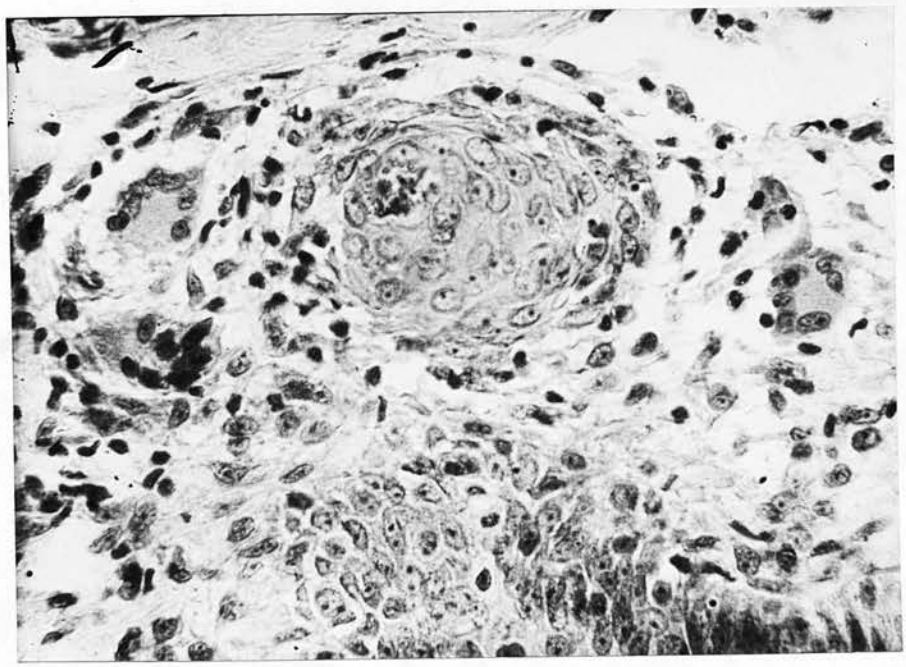


PLATE 37.

An enlargement of Plate 36 to show the giant cells clearly.

(Haematoxylin and eosin. X 390)

with the clinical occurrence of mammillaria with sweating. The rapid alteration, within a few minutes, of the size of the elevation is also explicable by increases and decreases of filtration pressure as blood flow increases and decreases.

The slow resolution of mammillaria is also explained. These oedematous spaces can only be formed by the splitting of the collagen fibre network of the superficial dermis. They can only disappear if the collagen network is reformed, as appears to be happening in some of the sections, but this is inevitably a slow process. The oedema fluid will effectively screen the blood-filled plexus and so make the elevations appear pale to the observer. In fact, the sections suggested that within the oedematous areas the blood vessels are less full than elsewhere, perhaps due to the pressure of the oedema. The depth of the lesions explains an observation made at Karachi that it was possible to sandpaper the epidermis off till the dermal papillae bled without affecting the appearance of mammillaria.

But it is also clear that this change in the skin is only a quantitative change from the normal and from prickly heat. There was always a small perivascular space in normals, and in some cases of prickly heat this was enlarged, up to mammillaria size. But in prickly heat the distension was usually much less than in mammillaria, and it was more patchily and less universally distributed. Similarly the focal subepidermal oedema around sweat ducts occurred in some cases of prickly heat but less frequently than in mammillaria.

While at Karachi mammillaria only appeared to develop when prickly heat /

heat cleared up (although prickling and vesicles occasionally reappeared when sweating began to return even although the mammillaria was still present), other observers have commented on the two conditions occurring simultaneously, mammillaria being visible "under" prickly heat. This latter observation is compatible with the histological explanation given above.

The sweat-secreting apparatus in anhidrotic heat exhaustion.

Two technical matters are important to the consideration of possible histological lesions to the sweat glands and their ducts. The sweat gland acini undergo rapid post-mortem decomposition. In 1946 a direct comparison of fixation with formol-saline and with Susa was made. This suggested that formol-saline did not penetrate the skin fast enough to fix the sweat gland acini even when biopsy specimens were immersed in fixative immediately they were removed from the body. The more rapidly penetrating mercuric chloride in the Susa, however, seemed to ensure that most normal sweat gland acini consisted of plump, palely eosinophilic cells.

The second technical deficiency is the impossibility of ensuring that all the keratinised parts of the skin will be found in the final preparation. As stated in another investigation (McCance and Barrett, 1951), "The desquamation and scaliness, which were often so conspicuous clinically, were inconspicuous histologically". This technical deficiency is directly relevant when assessing the evidence for the hypothesis that abnormal keratin plugs in sweat ducts may obstruct the outflow of sweat.

A direct count showed that there were approximately the same number

of sweat glands per linear centimetre of skin section in normals and in anhidrotic heat exhaustion. There was therefore no marked congenital or acquired deficiency in the number of sweat glands in anhidrotic heat exhaustion. The sweat gland acini in cases of anhidrotic heat exhaustion were not normal though it was sometimes difficult to specify the abnormality precisely (Plates 38,39,40). The normally plump eosinophilic cells were paler, sometimes vacuolated and sometimes flattened. Sometimes there appeared to be a metaplasia of secreting epithelium into non-secreting duct epithelium. The lumen of the tubule might appear wider than normal from shrinkage of the acinar cells, but the over-all diameter from basement membrane to basement membrane was not altered (Plates 41,42,43,44). This was checked by measurement. The sweat gland tubule sometimes appeared to be shorter than usual, and this was confirmed by direct enumeration of the number of times a tubule was cut in any one section. The longer the tubule the more numerous the coils and the larger the number of tubular cross-sections in any one place. The data are as follows, and show clearly the smaller size of the tubule in anhidrotic heat exhaustion.

PLATE 38.

Normal sweat gland in a subject with mammillaria and "normal" sweating.

(Haematoxylin and eosin. X 140)

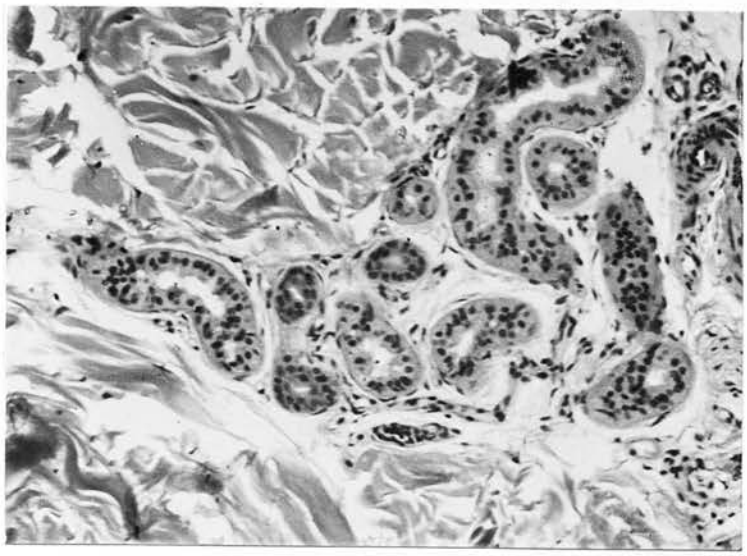


PLATE 39.

Normal sweat gland in a subject with severe sunburn.

(Haematoxylin and eosin. X 130)

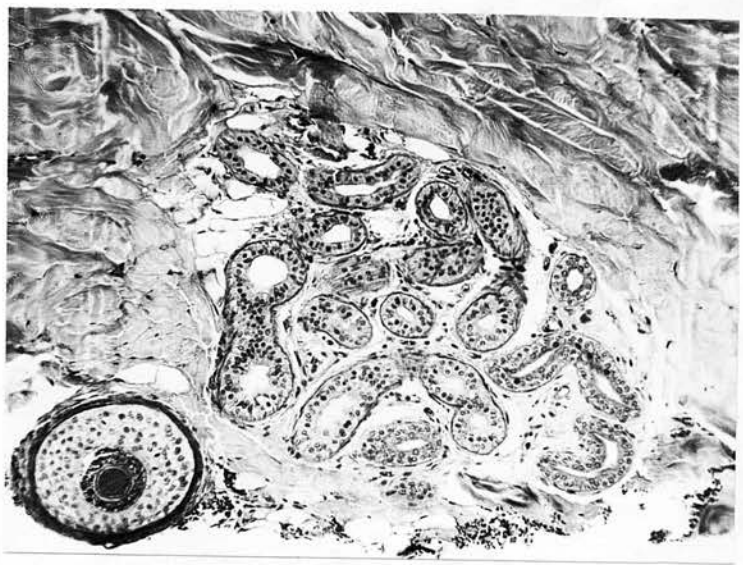
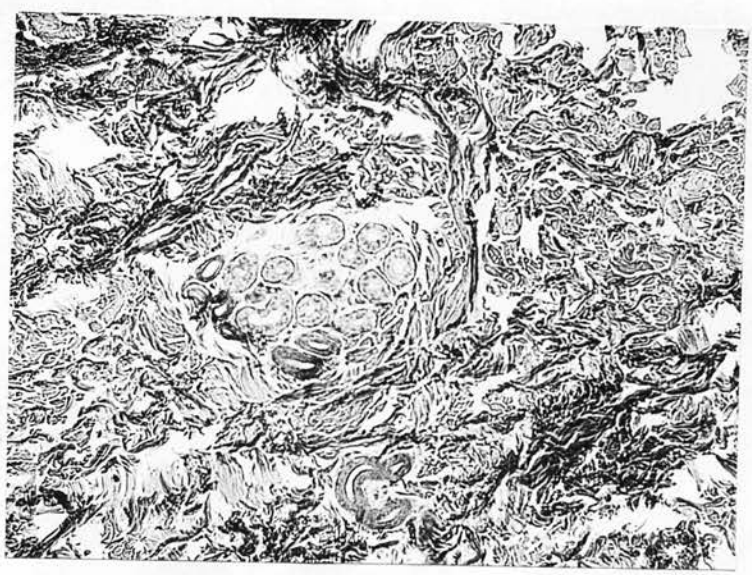


PLATE 40.

Normal sweat gland in a subject with prickly heat severe enough to require admission to hospital.

(Haematoxylin and eosin. X 70)



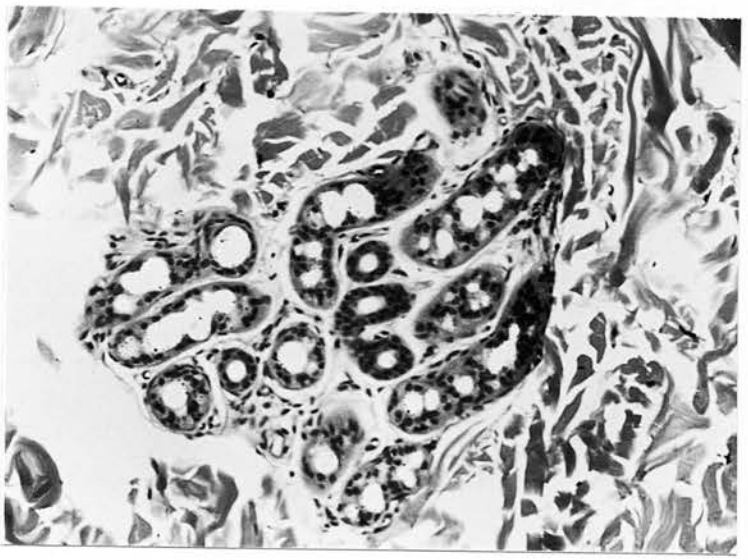


PLATE 41.

Abnormal sweat gland in a subject with anhidrotic heat exhaustion.

(Haematoxylin and eosin. X 140)

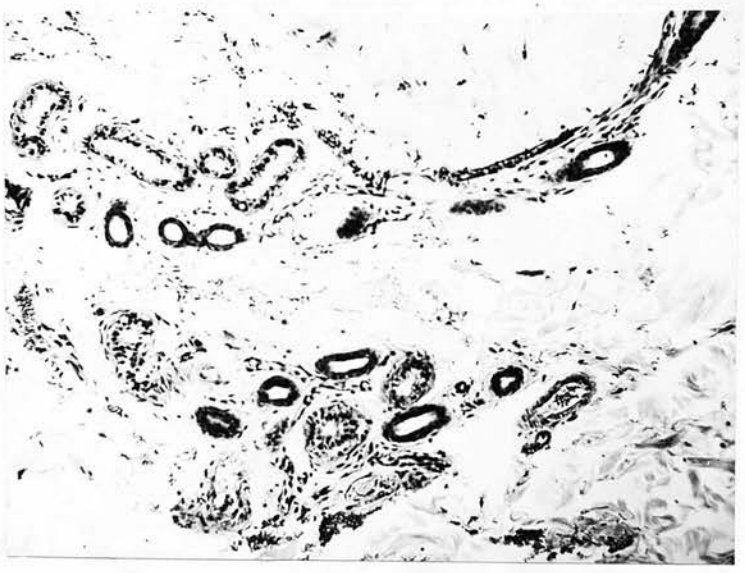


PLATE 42.

Abnormal sweat gland in a subject with anhidrotic heat exhaustion.

(Haematoxylin and eosin. X 140)

This was one of the most abnormal glands encountered.

PLATE 43.

Abnormal sweat gland from a subject with anhidrotic heat exhaustion.

(Haematoxylin and eosin. X 70)

PLATE 44.

Abnormal sweat gland from a subject with anhidrotic heat exhaustion.

(Haematoxylin and eosin. X 70)

	Normal	Anhidrotic heat exhaustion
No. of subjects	7	8.
No. of sweat glands measured	58	56
Mean no. of tubular cross-sections per gland	17	11
Range of means for the subjects in each group	13-27	9-13
Proportion of sweat glands with more than ten cross-sections of secreting cell tubule	45	12
Proportion of sweat glands where more than half of sectioned tubules were lined with duct epithelium (omitting all glands with less than six sectioned tubules)	17	43

There was no overlap between normals and cases of anhidrotic heat exhaustion in the mean number of tubule cross-sections per gland. There was a highly asymmetric frequency distribution of cross-sections per gland, however, since the periphery of many glands was all that showed, and these inevitably gave a small number of tubule cross-sections.

The mean is not necessarily the best parameter to use for comparisons so two additional estimates were made. Sweat glands which had a reasonable amount of secreting tissue were thought to be those with at least ten sections of tubules lined by secreting cells. There was nearly four times as high a proportion of such glands in normals as in cases of anhidrotic heat exhaustion. Also, the proportion of duct epithelium in the sweat gland tubule was estimated for all glands of any size. In anhidrotic heat exhaustion nearly half the tubules sectioned were lined by duct epithelium. These numerical data therefore support the conclusion that

in /

anhidrotic heat exhaustion the sweat secreting tubules are shorter than normal and have relatively more duct epithelium. Actual micro-dissection of tubules would be needed for proper proof, and this has not been attempted. Nevertheless, it is safe to conclude that there is an atrophy of the whole coiled gland as well as of its component cells, but that the atrophy is not absolute. From the histological structure it would be impossible to guess that secretion had in fact ceased altogether from the sweat glands and, although the numbers of subjects are small, there seemed to be no quantitative difference between subjects with anhidrotic heat exhaustion in whom sweating had returned and those who were still dry.

The ducts of the sweat glands were normal throughout their course from the coiled tubule to the epidermis except for the focal periductal lesions described earlier. The ducts were not dilated and obstruction of the ducts was not seen at any level. Occasionally at the mouth of a duct a mass of keratin occupied the lumen but there was always some luminal space. With the reservation already made about the possible fallacy of concluding that keratin was absent, it must be said that the material from Karachi did not lend any support to the hypothesis that obstruction at the mouth of the sweat ducts is the cause of anhidrosis. There was no direct evidence of an obstructing agent and no indirect evidence, such as dilatation of the sweat duct or tubule, to suggest that there had been a functional obstruction. The only dilated sweat ducts seen were found in two subjects, each of whom had two biopsies, with prickly heat and without (Plate 45). There was no difference in the degree of dilatation, which is /

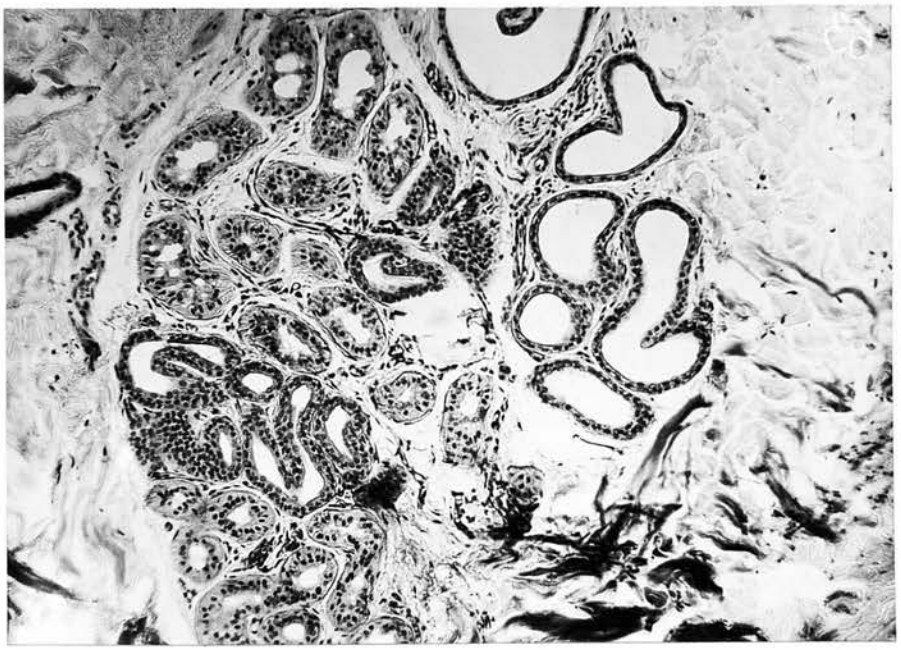


PLATE 45.

Normal sweat gland with dilated ducts in a subject with prickly heat.

(Haematoxylin and eosin. X 130)

His sweat ducts were seen to be equally dilated in a biopsy taken before he had prickly heat, but on neither occasion were the ducts dilated in their terminal parts in the superficial dermis or epidermis.

is believed to have been an individual characteristic.

Histological lesions with no apparent clinical counterpart.

Occasionally the mouths of sweat ducts were occupied by polymorphonuclear leucocytes even in a normal subject (Plates 46,47). Occasionally too there was a collection of "round cells" in a space adjacent to a sebaceous gland. Sometimes a proportion of these cells were polymorphs. Sweat glands too could be similarly infiltrated. In one case of anhidrotic heat exhaustion a sweat gland was very heavily infiltrated with cells which were almost purely polymorphonuclears, so that the gland was almost completely disorganised. The interesting feature was the lack of necrosis of the tissue so heavily infiltrated and the absence of micro-organisms from the lesion (Plate 48). It is possible that this lesion was the first stage of a hydradenitis, the inflammatory sweat gland lesion which occurs under the same climatic conditions as anhidrotic heat exhaustion (chapter 17).

Discussion.

These histological findings are unfortunately largely negative. In mammillaria a vascular-oedematous explanation was found for the clinical appearance and since in many ways mammillaria is merely an exaggeration of the normal "micro-contours" of the skin, this is perhaps a satisfactory conclusion. A micro-anatomical explanation of the ordinary skin fissures and grooves does not apparently exist. In prickly heat there was no histological counterpart for the flaking keratin, the erythema and the oedema /

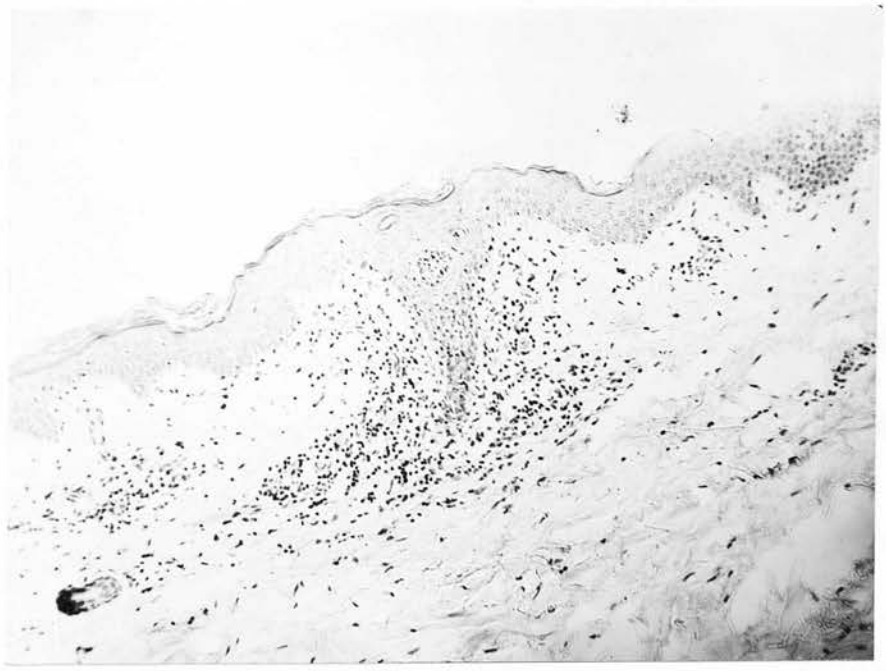


PLATE 46.

A symptomless lesion in a subject who had had prickly heat and was normal at the time of biopsy.

(Haematoxylin and eosin. X 110)

Polymorphonuclear leucocytes in the lumen and wall of a sweat duct. Around the sweat duct is an oedematous space extending more deeply to the "mammillaria level".

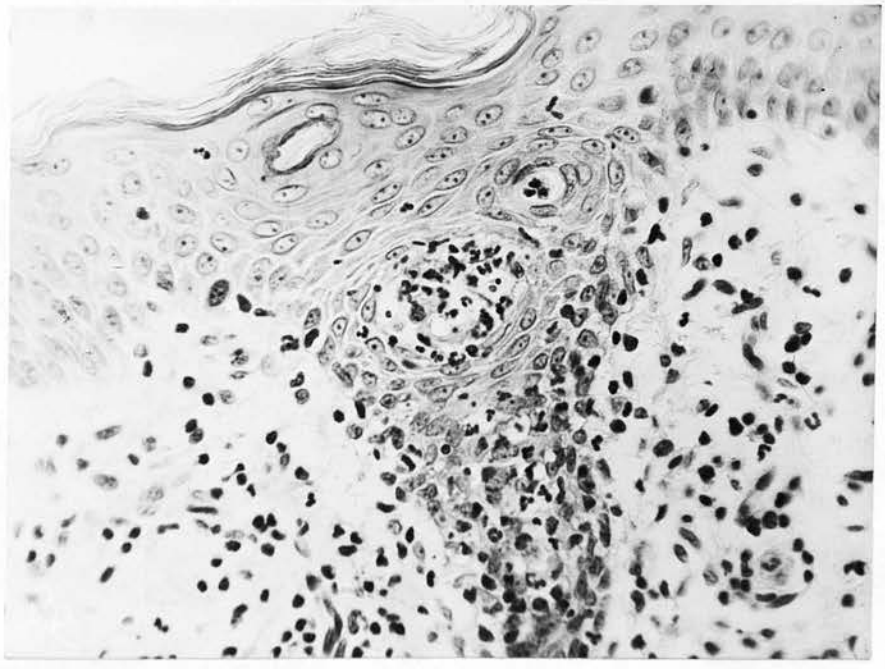


PLATE 47.

Enlargement of Plate 46. (X 390)

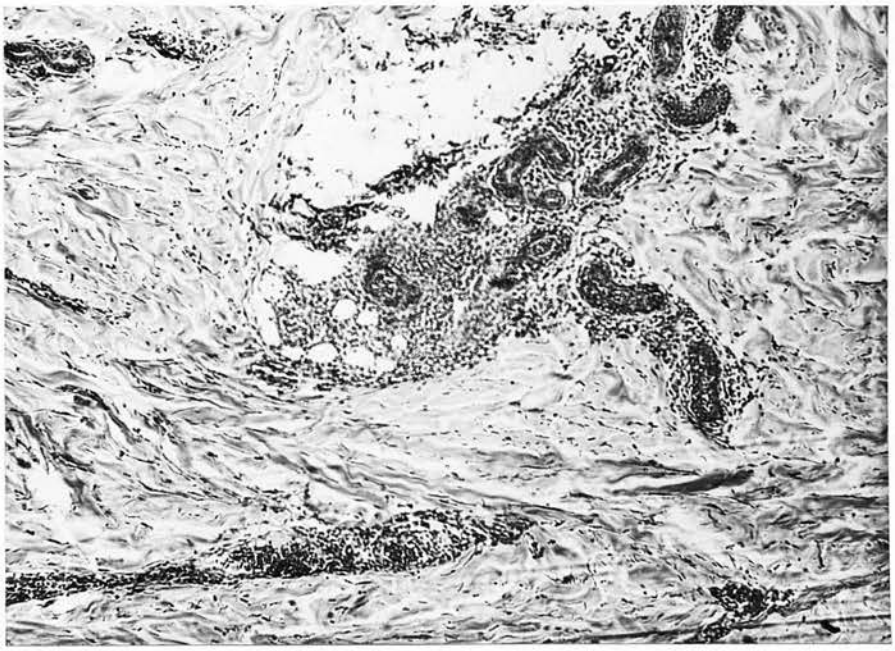


PLATE 48.

A sweat gland heavily infiltrated by polymorphonuclear leucocytes in a subject with mammillaria.

(Haematoxylin and eosin. X 70)

No micro-organisms were seen in specially stained serial sections.

oedema, and no structural explanation for the subjective symptoms of prickling and pruritus. But since cooling of the skin immediately removes the symptoms, and cooling for twentyfour to fortyeight hours the erythema and oedema, perhaps no structural lesion should be expected in histological sections. More important, perhaps, are the anatomically normal sweat glands in prickly heat in spite of the deficiency in sweating. The same is true of sunburn, three biopsies of which were obtained at a time when sweating was greatly reduced. In prickly heat it is now widely accepted (O'Brien, 1947, 1948, 1950; Shelley et al., 1950; Shelley, 1951; Sulzberger et al., 1946) that the sweating deficiency and vesicles are due to an obstruction of the sweat ducts, and the same hypothesis has been put forward as the explanation of mammillaria and of the anhidrosis of anhidrotic heat exhaustion (O'Brien, 1948, 1950; Shelley, 1951). No such obstruction was found in the Karachi material, and the evidence for the hypothesis will need to be discussed fully. Meanwhile it should be admitted that no complete alternative explanation is put forward, and it is also emphasised that there is as yet no evidence that the deficient sweating in prickly heat is absolute (as it is in anhidrotic heat exhaustion) and not merely the expression of some local alteration in the normal chemical and nervous stimuli for sweating.

The sweat duct obstruction hypothesis proposes that clinically deficient sweating in prickly heat is due to the inability of the sweat to appear on the surface of the skin, not to failure of secretion by the sweat glands. Continued activity of these glands leads to rupture of the /

the sweat duct within the epidermis and the formation of a vesicle of sweat. In mammillaria the rupture occurs deeper within the skin so that the leaking sweat forms a vesicle in the papillary layer of the dermis. The hypothesis assumes that duct obstruction and the visible skin lesion (prickly heat or mammillaria) occur together, so that vesicles cannot occur without duct obstruction, nor duct obstruction without vesicles. It is now quite clear, however, that the anhidrosis and visible skin lesions do not always occur together, e.g. the anhidrosis of skin not showing mammillaria on the forearm in anhidrotic heat exhaustion, and the peripheral zone of deficient sweating around the visible lesion of prickly heat. Also, the number of vesicles in prickly heat is always much fewer than the number of sweat ducts in the same area, and prickly heat without vesicles also sometimes shows deficient sweating.

If the obstructive hypothesis is to explain these facts an additional assumption is necessary, that obstruction of a sweat duct from a healthy actively secreting sweat gland does not necessarily lead to rupture of a duct. In these circumstances, however, any obstruction must obviously lead very rapidly to cessation of secretion of sweat by the sweat gland. The sweat duct obstruction theory can account for vesicle formation but must also postulate that a large proportion of sweat glands fail to secrete more than a very tiny amount of sweat. Observations have been described which suggest an alternative mechanism for vesicle formation. Sweat duct obstruction is therefore an unnecessary postulate since the most economical hypothesis is that the sweat glands fail to secrete ab initio.

Further /

Further, the actual histological observation that there is in fact a sweat duct obstruction is open to criticism on three counts: first, that it is impossible to demonstrate histologically complete obstruction to the flow of fluid along a tube which is shaped like the terminal portion of the sweat duct; second, that there is none of the expected indirect evidence of obstruction, no dilatation of the sweat duct or sweat gland tubule, or lengthening of the tubule; and third, that the keratin ring, which was believed to be the obstructing agent, is not regularly present in all sweat ducts as it should be.

The sweat duct obstruction theory is clearly attractive because it collects under one aetiological heading quite a number of superficially diverse lesions. Detailed consideration, however, has shown that it is not really satisfactory, though discarding the theory introduces its own difficulty. Why do normal looking sweat glands in prickly heat fail to secrete, and why are the sweat glands of anhidrotic heat exhaustion not more abnormal in appearance?

Summary /

Summary.

(1) A full description is given of mammillaria, the characteristic change in the skin which follows severe or moderately severe prickly heat in a humid climate. In a dry climate it is possible that the change does not occur.

(2) Mammillaria is often associated with alterations in the quantity of sweating. Over the affected areas sweating may be reduced, while elsewhere it may be increased. Mammillaria itself is symptomless apart from a feeling of warmth and "fullness" under the skin on exposure to heat stress. However, the associated reduction in sweating may lead to other symptoms.

(3) Mammillaria appears to be an invariable feature of anhidrotic heat exhaustion in humid climates, probably because severe prickly heat is a common antecedent factor in both conditions. In a hotter and drier climate, just as prickly heat is apparently often not succeeded by mammillaria, so anhidrotic heat exhaustion often occurs without this skin change.

(4) Biopsies of the skin from normal subjects and from subjects with mammillaria, prickly heat, and anhidrotic heat exhaustion are described.

(5) The superficial vesicles of prickly heat appeared to be caused primarily by a break in the basal layers of the epidermis.

(6) /

(6) The elevations of mammillaria appeared to be caused by large oedematous spaces around the blood vessels of the papillary layer of the dermis.

(7) The sweat glands of prickly heat were normal, and the ducts did not seem to be obstructed.

(8) The sweat glands of anhidrotic heat exhaustion were partially atrophied; the histological damage seemed insufficient to account for a complete anhidrosis.

(9) No evidence for sweat duct obstruction was obtained, and this hypothesis is considered unsatisfactory as an explanation of vesicle formation and sweating deficiency.

CHAPTER 13.

COMPARATIVE PHYSIOLOGICAL OBSERVATIONS ON PRICKLY HEAT, MAMMILLARIA AND ANHIDROTIC HEAT EXHAUSTION.

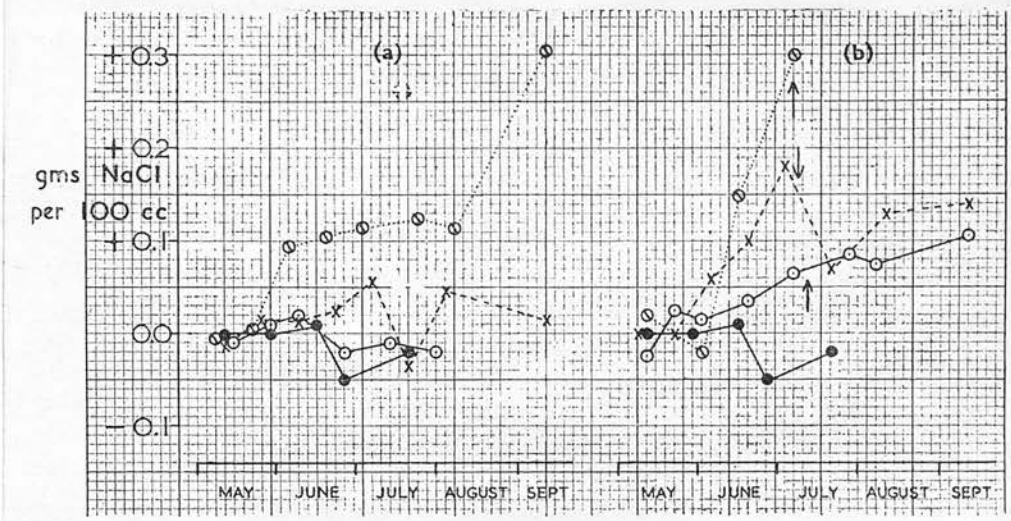
The association of a high sweat chloride, prickly heat and mammillaria.

Cases of anhidrotic heat exhaustion at Karachi secreted sweat with an abnormally high concentration of chloride (Table IV, page 143), and a similar finding was recorded at Shaiba by Ladell et al. (1944). At Karachi high values were also obtained from subjects with mammillaria (Table IV). Prickly heat invariably preceded mammillaria, and it was of interest to determine at what stage of the sequence the sweat became abnormal. This was done in 1947 by examining a number of normal subjects in May and at intervals during the summer.

The results in those who were followed for three months or longer are recorded in Figure 7 and the following conclusions can be drawn. The mean sweat chloride concentration was constant in normal subjects and no consistent alteration occurred during the summer. This was also true of those subjects who developed prickly heat but no mammillaria, except for two individuals after their second attack of prickly heat who are discussed later.

Subjects who developed prickly heat and then mammillaria showed a rise in sweat chloride. The rise was greater the more severe the mammillaria /

FIG. 7



Changes in sweat chloride during the summer. The baseline for each clinical group is the mean of the first two observations on each individual in the group.

	Number of subjects.	*Baseline sweat chloride in g. NaCl per* 100 *c.c.*	
Normals	4	0·16	●
Prickly heat developing late	10	0·22	⊙
„ „ early and prolonged	7	0·20	×
„ „ „ , with a second attack after a free interval...	2	0·17	⊘
Mammillaria slight	3	0·15	⊙
„ moderate	3	0·15	×
„ severe	2	0·20	⊘

The serial observations were grouped in periods of 1 or 2 weeks, each containing one observation from each subject except in the three largest clinical groups where not every subject was examined in each period. For each period the deviation of the group mean from the baseline of the group is charted as the change in sweat chloride.

The first four groups are shown in Graph (a) : the three mammillaria groups and the normals in Graph (b).

The arrow shows the time when mammillaria was first seen.

mammillaria, but occurred during the stage of prickly heat before mammillaria was visible. The evidence suggests that there was no further increase in sweat chloride after the mammillaria was first seen.

In 1947 none of the subjects picked for serial investigation developed the syndrome of anhidrotic heat exhaustion so that it was not possible to demonstrate that the sweat chloride rose still further with the onset of the syndrome as suggested by the results in Table IV (page 143).

In subjects with prickly heat and a constant sweat chloride the prickly heat was mild, and it is likely that the failure of the sweat chlorides to rise and the failure of mammillaria to develop were both dependent on the mildness of the prickly heat.

In the group of subjects who developed prickly heat late in the season the sweat chloride was initially somewhat high. This was due to two individuals whose sweat chloride averaged 0.37 and 0.29 gm. NaCl. per 100 c.c., both above the normal range. One subject in the group who developed prickly heat early, also had a high sweat chloride averaging 0.31 gm. NaCl. None of these three subjects showed mammillaria, and their sweat chloride remained stationary throughout the period of observation. The evidence is insufficient to support the possibility that a naturally high sweat chloride predisposed to prickly heat.

Two subjects already mentioned showed, after their second attack of prickly heat, a rise in sweat chloride as great as the cases of severe mammillaria. These individuals were anomalous in a number of other respects. /

respects. Their sweat pH was more alkaline and their skin temperatures higher than normal, both features of mammillaria, as will be shown later. It is possible that, in the four weeks interval between the last two examinations of sweat, mammillaria had developed and then cleared up, but on the other hand, even at the time of their first attack of prickly heat, their sweat chloride concentration showed a rise as great as moderately severe cases of mammillaria (Figure 7). Thus there is a possibility that these functional changes in sweat composition are more fundamental than, and not invariably accompanied by, mammillaria. Even in subjects with mammillaria the sweat was collected from those areas of the arm which are normally free from mammillaria so that the abnormalities of the sweat cannot be the direct consequence of the abnormality of the skin.

Observations made in July 1947 at Cawnpore by Dr. M. A. Floyer (personal communication) showed that the sweat chloride there was much higher than at Karachi, averaging 0.54 gm. NaCl per 100 c.c. in seven cases of severe prickly heat. The severity of the prickly heat was such that all the men would have been expected to develop mammillaria if they had been at Karachi. A fortnight later three of the men were free from prickly heat and three were considerably improved. Mammillaria was not seen and the sweat chlorides had all decreased except in the individual in whom severe prickly heat persisted. Thus at Cawnpore, in contrast with Karachi, individuals with severe prickly heat and a high sweat chloride apparently failed to develop mammillaria when the prickly heat subsided. This difference from Karachi may be related to climatic differences /

differences which are discussed in chapter 11. Also, while at Cawnpore a high sweat chloride might rapidly return to normal, at Karachi once the sweat chloride rose to the mammillaria range, the high concentration persisted for many weeks or months.

These observations on sweat composition in the field at Karachi are of interest because they demonstrate pathological alterations which cannot be accounted for by the factors which are known to affect the sweat chloride of normal subjects (Johnson et al. 1944).

The variability of sweat chloride in anhidrotic heat exhaustion.

The chloride concentration of the sweat in anhidrotic heat exhaustion is not fixed but can be altered by physiological stimuli in the same direction as in normal subjects, although it was never found within the normal range. This was demonstrated in 1947 by two experiments.

Six cases of anhidrotic heat exhaustion during the recovery stage, and while the sweat chloride concentration was still very high, performed a standard indoor exercise on two successive days, on the second day thirty minutes after drinking a litre of distilled water. Each patient showed a reduction in the sweat chloride as a result of drinking water, and the mean reduction was 0.11 gm. NaCl per 100 c.c. This difference was not likely to have been due to chance ($P < 0.01$).

Four of these cases at the same stage of recovery performed the standard outdoor exercise clad in shirt and shorts soaked in cold water in order that the evaporation of the water should lower the skin temperature. /

temperature. Comparison with the results of the standard exercise performed in the ordinary way three days before and three days after showed that, as in normal subjects (Johnson et al.1944), cooling of the skin resulted in a reduction in the sweat chloride. The reduction occurred in every case, and averaged 0.17 gm. NaCl per 100 c.c. Sweat volume was also reduced in each case by the cooling, the reduction averaging 60 per cent.

Sweat pH.

Observations on the pH of the sweat were made during 1947 with a glass electrode but as the apparatus was not available until the end of July no serial investigations were possible and only small numbers of individuals could be examined. All the readings reported were made in the last week in July and the first week in August, except for some of the results in cases of anhidrotic heat exhaustion, which were obtained in September.

The results obtained on sweat from the standard outdoor exercise test are summarised in Table VII. The results in prickly heat were not significantly different from the normals. There was a trend of increasing pH with increasing severity of mammillaria but the most strikingly abnormal results were shown by cases of anhidrotic heat exhaustion, in whom the abnormal findings were confirmed by repeated examinations. One third of all the readings in this group was higher than the highest reading of any /

TABLE VII.

Comparative estimations of sweat pH and skin temperatures.

		Sweat pH.			Skin temperature (degrees C).			
		Number of subjects.	Group mean.	Range.	Number of subjects.	Group mean.		Range.
						Limbs.	Trunk.	
Normal	Free from prickly heat up to time of examination	5	5·6	5·3–5·8	10	33·4	33·3	32·3–33·8
Active prickly heat	First attack	6	5·5	5·2–5·8	7	33·5	33·4	33·0–34·2
	Second attack (1)	5	5·7	5·6–5·9	5	33·8	33·6	32·9–34·2
Mammillaria	Mild	3	5·5	5·4–5·6	3	33·5	33·5	33·4–33·6
	Moderate	3	5·8	5·7–6·0	2	33·8	33·7	33·1–34·4
	Severe	3	6·0	5·9–6·1	3	34·0	33·9	33·5–34·7
	Recovered (skin normal)	5	5·8	5·6–5·9	—	—	—	—
Anhidrotic heat exhaustion	Acute (2)	2	6·6	6·1–7·0	2	34·8	34·8	34·6–34·9
	On discharge to convalescent camp	6	6·0	5·6–6·5	6	34·0	34·0	33·5–34·4
	One month later, fit for duty	6	5·8	5·2–6·6	—	—	—	—

(1) Not including the two anomalous subjects discussed on p. 210.
(2) Sweating much reduced, symptoms easily provoked.
The outdoor exercise test was used in every case.

any other individual. The severest case gave values of 7.0 and 7.1 just before and just after a period of complete anhidrosis. Even after clinical recovery three out of six cases had a sweat pH greater than 5.9, the highest normal value.

It is believed that the abnormally high pH of the sweat was another index of abnormally functioning sweat glands. Other explanations are possible, e.g. that the high pH was due to hyperventilation and a consequent alkalosis. Lung ventilation, however, was much greater in the indoor than in the outdoor exercise test while the sweat pH was the same in both. This was also true in normal subjects.

Sweating in prickly heat.

Lipscomb (1944) stated that sweating was sometimes diminished in prickly heat, but Sulzberger and Zimmerman (1946) were able consistently to demonstrate a sweating deficiency from the second day after the onset and even after the active lesions had disappeared. The reduction in the active stage was confirmed at Karachi in 1946 and 1947, as shown in plate 5 (page 136). The effect on thermal equilibrium of the reduced sweating associated with prickly heat has still to be investigated, but it may not be important in the humid climates where prickly heat is also most severe.

Skin temperature.

Skin temperature after exercise was estimated with a simple thermocouple /

thermocouple and galvanometer. All the readings were obtained in one fortnight when environmental conditions were approximately constant. The temperature readings are not claimed to have any absolute value, but are of comparative value since the conditions under which measurements were made were identical for all subjects.

Table VII shows the mean skin temperatures of groups of individuals recorded immediately after completion of the standard outdoor exercise. As with sweat pH there was a small but steady rise with the severity of mammillaria, and a definitely abnormal finding in acute anhidrotic heat exhaustion. The changes in skin temperature found in all the groups would be expected from what has already been observed of the changes in the volume of sweat produced. In prickly heat where skin temperature was within normal limits sweating was reduced only in patches, while in anhidrotic heat exhaustion, where the skin temperature was at its highest, the reduction in sweating was extreme. Ladell et al. (1944) found a similar but much larger difference in the temperature of dry and sweating skin.

The conductivity of heat through the skin.

That deficient sweating is not the only factor interfering with the loss of heat from the body was demonstrated by an experiment in which a group of individuals were immersed up to the neck in a bath of water at 106 to 108 deg.F. for twenty minutes. The results are recorded in Table VIII, and show that cases with mammillaria, including those with anhidrotic /

anhidrotic heat exhaustion, absorbed less heat than normals as shown by the lower rectal temperature.

The simplest explanations of this phenomenon are an alteration in the specific conductivity of the skin, or an impaired blood flow through it. Support for the latter explanation is available in the clinical observation of the general pallor of the skin at rest, and the failure of the expected degree of flushing after stimulation by heat.

Cutaneous insensible perspiration.

Observations on the cutaneous insensible perspiration (using a modification of the method described by Felsher,1944) were made in 1947 in an air-conditioned room on a number of subjects with normal skin at the beginning of the hot season (April 21st to May 10th) and at the peak of the hot season (June 21st to July 12th). Observations were also made during the second period on subjects with prickly heat and on subjects with anhidrosis following prickly heat. In the former, prickly heat was present at the site where the estimations were made, and in the latter, estimations were made below the clavicle, where no glandular sweating was demonstrable, and on the epigastrium, where sweating had returned to a considerable extent.

The effective temperature (Bedford,1946) of the air-conditioned room varied from 67 to 74 deg.F., well below the minimum temperature for sweating (Evans,1945). Subjects entered the room after lunch and removed all their clothes. Then they lay recumbent for 45 to 60 minutes, naked /

TABLE VIII.

Rectal temperature ° F. after immersion in hot bath.

	Anhidrotic heat exhaustion.	Mammillaria.	Prickly heat.	Normal.
	100·6	100·4	101·1	102·3
	101·0	101·0	103·0	103·0
	101·0	—	—	—
	101·2	—	—	—
	101·8	—	—	—
Mean	100·1	100·7	102·1	102·7

TABLE IX.

Differences in cutaneous insensible perspiration in different types of subject, different areas of skin, and at different times of year.

Type of subject.	Region.	Number of subjects.	Cutaneous insensible perspiration (mg. per sq. cm. per hour).	Region.	Number of subjects.	Cutaneous insensible perspiration (mg. per sq. cm. per hour).
Early (21*st April to* 10*th May*)						
Normal	Epigastrium	11	1·5	Thigh	5	1·1
Late (21*st June to* 12*th July*)						
Normal	Epigastrium	7	1·2	,,	3	1·2
Prickly heat	,,	2	1·0	,,	1	1·9
		2	2·4			
Acquired anhidrosis	,,	8	2·0	Chest	4	1·6

TABLE X.

Differences in cutaneous insensible perspiration (normal subjects) over same area of skin, early and late in the hot season.

Subject.	Region.	Cutaneous insensible perspiration (mg. per sq. cm. per hour).		
		Early.	Late.	Difference.
1	Epigastrium	1·3	1·0	−0·3
2		1·5	1·0	−0·5
3		1·3	1·0	−0·3
4		1·8	1·3	−0·5
5		1·9	1·2	−0·7
5	Thigh	1·6	1·5	−0·1
6		1·2	1·0	−0·2
7		1·3	1·1	−0·2

naked except for a light towel, before the estimations were made. It can therefore be assumed that no sweating occurred during the experiments. The epigastrium and inner aspect of the thigh were chosen for convenience and because the epigastrium is a common site for prickly heat, and the thigh an infrequent site. Neither is a site of emotional sweating. The values obtained (Table IX) were in the same range as those of Felsher (1944) and Felsher and Rothman (1945) using the same method and at similar air temperatures. A regional difference was found as in other similar investigations (Kuno 1934, Burch and Sodeman 1944). Following exposure of the subjects for two months to increasing heat and humidity cutaneous insensible perspiration from the epigastrium was not increased but showed a decrease that was statistically significant (Table X). Estimations on the thigh also showed a decrease.

An abnormally high result was always obtained in subjects with acquired anhidrosis following prickly heat. In two of these subjects estimations were made more than once while they were living in an air-conditioned room. In each there was a steady decrease during this period in one of them from the high value of 2.8 to the normal value of 1.1 mg./sq.cm./hour in three weeks.

Over areas of active prickly heat an increase was found in two out of four subjects. In one the value was 76 per cent. higher than that over the same area of skin before the development of prickly heat, and in the other 30 per cent. higher.

The decrease in cutaneous insensible perspiration following prolonged exposure to heat may have been a consequence of acclimatization, or may have /

have been associated with an alteration in the reactivity of the skin to the relatively cold air of the room in which the estimations were made. At the height of the hot season, when the second group of estimations was made, goose-flesh was frequently noticed to appear when the subjects entered the air-conditioned room where the effective temperature was from 70 to 74 deg.F. This had not been noticed in the earlier experiments when the effective temperature was the same or lower.

Variations in the cutaneous insensible perspiration of the same order as observed here have been produced by an alteration in the degree of hyperaemia of the skin (Felsher and Rothman,1945), and by a difference of a few degrees C. in its temperature (Pinsen,1942). The results in cases of prickly heat and acquired anhidrosis may also have been caused by an increase in the temperature and vascularity of the skin, but Felsher and Rothman (1945) showed that hyperproduction of keratin was another factor. They suggested that the dehydration of the Malpighian cells in the process of keratinization provided some of the water lost in the insensible perspiration. If so, the hyper-keratinization which has been said to occur in prickly heat may have been responsible for the increase observed. The experiments of Burch and Winsor (1945), who found a similar decrease in the total insensible perspiration from a cool month to a hot humid month, are not strictly comparable, as the measurements included other factors as well as cutaneous loss.

Water diuresis and pituitrin tests.

Polyuria is one of the striking features of anhidrotic heat exhaustion. In 1947 some preliminary observations were made on the diuretic response to ingested water and are reported here in spite of their incompleteness.

Absolutely normal subjects were difficult to obtain in July and August in Karachi and the "normals" used included individuals who were suffering or had recovered from prickly heat, although it is recognised that alterations in salt and fluid balance appear to be associated with the appearance and disappearance of prickly heat (chapter 15). All the tests reported were carried out between 2 a.m. and 6 a.m. At Karachi the tests were made in an air-conditioned room (effective temperature 73 deg.F.) which the subjects entered several hours before the beginning of the test in order to eliminate sweating. Each subject emptied his bladder and was then given 15 minutes to drink the test quantity of distilled water. Urine was collected at set times from the end of this 15 minute period. The subjects lay down and dozed during the test and stood up only to urinate.

In some of the tests 1500 c.c. water was given as the test dose, but it seems likely that the smaller dose of 1000 c.c. was a more sensitive means of demonstrating a difference between normals and cases of anhidrotic heat exhaustion. Comparison of normals in Karachi and in the United Kingdom (Table XI A and B) suggested that environmental temperature may have /

TABLE XI.

Diuretic response to 1,000 c.c. distilled water.

	Number of subjects.	Volume in c.c. of urine excreted in half-hourly periods following ingestion of water.				Total volume of urine in c.c. excreted in 2 hr.	Environmental conditions.
		0–½ hr.	½–1 hr.	1–1½ hr.	1½–2 hr.		
A. Normals at Karachi	2	20	335	350	280	985	E.T. 73°, covered by sheet only
B. Normals in Britain	5†	200	300	315	160	980	E.T. 49–63°, under ordinary bedclothes
C. Normals ex-India*	2	115	255	290	250	910	
	1†	70	130	310	195	705	
Anhidrotic heat exhaustion							
D. in air-conditioned room, Karachi, 1.IX.47	The same two subjects	20	105	210	250	580	E.T. 73°, covered by sheet only
E. in hot room, Britain, 23.IX.47		95	170	160	140	565	E.T. 80°, covered by sheet only
F. in ordinary room, Britain, 1.XI.47		160	220	260	110	750	—
G. in ordinary room, Britain, 3.III.48		55	135	215	75	475	E.T. 63°, under ordinary bedclothes

† Means of two separate tests in each subject. * Had had mammillaria the previous summer in India.
E.T. = Effective temperature °F.

TABLE XII.

Effect of pitressin on water diuresis.

2·5 I.U. pitressin followed by 1,500 c.c. water.	Number of subjects.	Urine volumes in successive periods.			
		1st.	2nd.	3rd.	4th.
Normals free from prickly heat	4	65	45	240	415
„ with prickly heat	4	40	40	305	510
Anhidrotic heat exhaustion: Acute	2	30	30	90	225
Recovered ...	4	35	50	285	570
Subjects with asymptomatic sweating deficiency (hyphidrotics)	3	25	30	100	195
0·5 I.U. pitressin followed by 1,000 c.c. water.					
Normals (two with prickly heat)	3	20	20	100	245
Anhidrotic heat exhaustion: Acute	1	—	60	40	30

Urine was collected at hourly intervals after 1,500 c.c. water and at half-hourly intervals after 1,000 c.c.

have altered the pattern of response, the diuresis being delayed in the warmer surroundings. An even greater delay in the diuresis occurred in cases of anhidrotic heat exhaustion. The total output of urine in normal and recovered subjects approximated the quantity of water drunk, but in cases of anhidrotic heat exhaustion the output was less than the intake during the observation period.

None of these findings appears capable of a simple interpretation and they are recorded here in the hope that they may stimulate further work. Two other points are also of interest in this connection. The two subjects with severe anhidrotic heat exhaustion still showed an abnormal diuretic response six months later after a normal English winter (two normal controls tested on the same night gave a normal response). One of the three individuals who had been observed to have mammillaria the previous summer also showed a somewhat abnormal response after return to this country (Table XI).

Other water diuresis tests were made after the intra-muscular injection of pitressin (Parke Davis) at the beginning of the water-drinking period. The results (Table XII) suggest that, after recovery, cases of anhidrotic heat exhaustion behaved like normals, whereas at an earlier stage pitressin had a more prolonged effect. The apparent sensitivity to pitressin in anhidrotic heat exhaustion may indicate that in these cases there is a higher natural blood level of pituitary hormone which would be compatible with the delayed diuresis to water alone. On the other hand, the prolonged action of pitressin may merely indicate a decreased /

decreased rate of inactivation after injection. It is an open question whether these abnormalities were constitutional and predisposed the affected individuals to develop their particular type of heat effects, or whether the abnormalities were the consequence of those heat effects, and further investigation is clearly necessary.

Summary.

(1) A raised sweat chloride and a decreased conductivity of heat through the skin were present in cases of mammillaria whether the anhidrotic syndrome was also present or not.

(2) The sweat chloride began to rise while prickly heat was present and before the mammillaria had become visible. A raised sweat chloride might thus be associated with severe prickly heat since it was often after severe prickly heat that mammillaria developed. In some cases of severe prickly heat the sweat chloride was high even though mammillaria failed to develop later, and it is possible that this occurs more often in a dry climate than a humid one.

(3) A high sweat pH approaching neutrality, and a high skin temperature were found only in anhidrotic heat exhaustion.

(4) The reduction in sweating in areas of active prickly heat was confirmed.

(5) /

(5) After exposure for two months to a hot and humid environment the cutaneous insensible perspiration in normal subjects was unaltered or decreased. It was increased in every case of acquired anhidrosis, and in two out of four cases of prickly heat.

(6) In cases of anhidrotic heat exhaustion there was a delay in diuresis after the ingestion of water and a prolongation of the anti-diuretic action of pitressin. There was some evidence that the delay in diuresis may persist for many months even after return to a temperate climate.

CHAPTER 14.

SENSITIVITY TO ATROPINE IN ANHIDROTIC HEAT EXHAUSTION.

One of the subjects[1] who had anhidrotic heat exhaustion in 1946 was admitted to the Hospital as an emergency in June 1947 for appendicectomy. The operation was carried out in an air-conditioned theatre, and the patient was found to have an uncomplicated acute appendicitis. However, at the end of the operation it was noted that he was very hot and that his skin was dry. The oral temperature was 103 deg.F. He was therefore retained in the theatre for an hour, by which time his temperature had nearly returned to normal, and then transferred to the ward. On the day after the operation the skin was normal and moist and there was no evidence of prickly heat. He made an uneventful recovery, and no evidence of any other disease was found.

About a month before the operation he had been examined during a review of the cases of anhidrotic heat exhaustion that had occurred in 1946, and the appearance of the skin and sweating function were normal. He had received ¼ gr. morphine and 1/100 gr. atropine sulphate half an hour before the anaesthetic (pentothal, gas and oxygen). No other similar incident occurred in the operating theatre during 1947. It was therefore concluded that the pyrexia immediately after the operation was due to interference with sweating caused by undue sensitivity to atropine.

It /

---

1 Mummery.

It was decided to investigate the possibility of sensitivity to atropine in this subject and in others who had had anhidrotic heat exhaustion.

Method.

Sweat was collected by means of a standard indoors exercise. The subject rested for thirty minutes before entering the room and performing the exercise, and when the effect of atropine was to be tested, atropine sulphate, gr. 1/100 was injected subcutaneously at the beginning of the resting period. The exercise was performed by most subjects on three occasions, on the first and third occasions without atropine, and on the second, following atropine. The three exercise periods were usually on successive days, and the longest interval between the first and last was six days (inclusive). Several subjects completed the series twice. Three groups of subjects were tested: (1) normals; (2) subjects who had had anhidrotic heat exhaustion in 1946; and (3) cases of anhidrotic heat exhaustion in 1947, after complete clinical recovery.

Results.

The results of the experiment are shown in Table XIII, and reveal that atropine caused bigger proportionate reductions in the volume of sweat in subjects who had had anhidrotic heat exhaustion, whether recently or a year previously, including the operation case (subject 9). The abnormally low sweat volume produced by subject 10 during his second control /

TABLE XIII.

Effect of atropine on sweat volumes during standard exercise.

Group	Case no.	Sweat volume in c.c.			Volume with atropine as per cent. of control mean $\frac{200b}{a+c}$		Group mean
		Preceding control (a)	With atropine (b)	Succeeding control (c)			
Normal	1	9.0	6.5	9.5	70		49
	2	15.0	4.0	15.0	27	54	
		15.0	10.0	10.0	80		
	3	9.5	3.5	9.5	37		
	4	10.5	4.0	12.5	35		
Anhidrotic heat exhaustion 1947, after clinical recovery	5	13.0	4.5	-	35		21
	6	7.0	1.0	-	14		
	7	11.0	1.5	-	14		
Anhidrotic heat exhaustion 1946; normal 1947	8	18.0	5.0	15.0	30		14
	9	12.0	0.75	14.0	5	11	
		13.0	2.0	12.5	16		
	10	8.0	Nil	0.75	Nil	Nil	
		6.5	Nil	3.0	Nil		

control exercise period coincided with clinically evident reduced sweating. It was possible that his hyphidrosis had been precipitated by the atropine administered at the previous exercise period.

Estimations of the chloride concentration of all the samples of sweat were made, but there was no consistent alteration associated with the atropine.

The exercise was quite a severe one and when the sweat volume was much reduced by atropine the subject became considerably distressed and the exercise was completed with difficulty.

Discussion.

It has been demonstrated that cases of anhidrotic heat exhaustion were more susceptible to atropine than normal subjects, not only immediately after clinical recovery when the sweat glands might not have resumed their normal function (subject 5, 6, 7), but also in the succeeding year, when there was no evidence of sweat gland dysfunction and the skin was normal (subject 8 and 9). It was not possible to discover whether the sensitivity to atropine was a direct result of having had anhidrotic heat exhaustion, or whether it was due to some constitutional abnormality of the structure, function, or even number, of sweat glands, which would also make the subject more susceptible to the syndrome.

A history of anhidrotic heat exhaustion should lead to caution in the use of atropine, since sensitivity to this drug may have serious consequences, especially in a hot environment. Even hyphidrosis, without symptoms /

symptoms of exhaustion, may be a potential danger. In the tropics heat stroke has been recorded following the administration of atropine as a premedication for anaesthesia (Love,1919, Morton,1944), as treatment for Parkinsonism (Segerdahl,1934), and as treatment for duodenal ulcer (Drew,1944).

Summary.

It has been demonstrated that subjects who have had anhidrotic heat exhaustion are abnormally sensitive to atropine. The clinical significance of this finding is discussed, and a case is described in which post-operative anhidrosis and pyrexia occurred.

CHAPTER 15.

THE EFFECT OF WATER AND SALT INTAKE ON PRICKLY HEAT.

Prickly heat is exceedingly common among white people living in a hot climate, especially if the climate is also humid. It is usually considered a minor disability, but the protracted discomfort it causes may seriously affect working efficiency and even health.

Experiments in a hot chamber at the U.S. Naval Medical Research Institute (Blum et al.1945) were concerned mainly in delimiting the climatic factor in the aetiology of prickly heat, and no record has been found of any other controlled investigation under tropical conditions. The experiment reported here was prompted by the observation that an increase in intake of sodium chloride was followed by severe prickly heat.

> A doctor who had been free from prickly heat on the North African coast travelled to Karachi, India, by air, and at the same time began to take extra salt because he felt he was now to live in a truly tropical heat. Though the climate was probably no worse than the one to which he had been accustomed, he developed a very severe attack of prickly heat after a few days.
>
> Another doctor, whose duties were divided between Karachi, a humid place, and Cawnpore, a hotter but drier place, found that at Cawnpore he was free from prickly heat and had to increase his salt intake to avoid hypochloraemia, but that, on returning to Karachi by air, he developed prickly heat, which subsided only when he ceased taking the extra salt.

Several other similar histories agreed in incriminating an additional

intake /

intake of sodium chloride as an aetiological agent in prickly heat, and in the late summer of 1946 several cases of prickly heat were treated by reducing salt intake and increasing water intake. The prickly heat of the treated patients improved, and of the untreated controls remained stationary; but, since the weather also improved at the same time the result was inconclusive. In 1947 the investigation was repeated earlier in the summer, when the climate was, if anything, steadily becoming hotter and damper.

Method.

The subjects of the experiment were 10 members of the staff of the R.A.F. General Hospital, Karachi, who continued their usual duties during the whole period of the investigation. They ate the normal staff food, which was cooked with liberal additions of salt, but no additional daily prophylactic salt ration was taken. During periods of increased water intake the subjects ceased to add salt to their food at table and drank 8 to 12 pints of water daily in addition to their usual fluid intake. Drinking such large quantities of water was difficult, and the diuresis inconvenient, but the investigation of 1946 had suggested that an additional intake of at least 8 pints daily was necessary for an effect on prickly heat. Continuous supervision of the water-drinking over several weeks was impossible, but co-operation was usually excellent. Selection of cases for the experiment was not influenced by the degree of co-operation expected. /

expected. During periods of increased salt intake fluid was reduced to the normal habit in this respect and additional table salt taken. The quantity was not measured, but the salt was added liberally to all meals and sometimes to drinking-water. It is estimated that 10 to 15 g. daily was taken in this way.

The subjects were examined at irregular but short intervals, and on each occasion the severity of the prickly heat was assessed. There seems to be no adequate clinical description of prickly heat, and this matter is too confused for discussion here. The most important features are the subjective sensation of prickling, which may occur even when the skin appears to be normal, and the objective erythema, which is distributed patchily and may be symptomless. Superficial epidermal vesicles are often but not invariably present. An arbitrary grading was adopted which took into account both the objective and subjective aspects, since discomfort in prickly heat may bear little relation to outward appearance. The days on which the men were examined are indicated in the accompanying figure, where severity is shown by the height of the black areas. Fluctuations reported as occurring between examinations are also shown.

Results.

The initial effect of increasing water intake in persons with prickly heat was sometimes an increase in discomfort, but this passed off in a few hours. After two or three days a definite improvement was usually noted, and in 8 of the 10 persons the prickly heat was eventually much improved /

improved or completely relieved (Figure 8). Sometimes improvement was delayed for as long as ten days, and the impression was gained that the rate of improvement was proportional to the degree of co-operation obtained in drinking the large quantities of water prescribed.

In 5 persons the prickly heat was aggravated or brought on anew when an increased salt intake was substituted for an increased water intake. This deterioration was more rapid and more striking than the earlier improvement on increased fluid. In 2 persons (cases 2 and 3) it was necessary to cut short the second period of increased salt intake because of the excessive discomfort produced. In all 5 cases improvement with a high water intake was demonstrated on a second occasion.

The figure shows that the fluctuations in prickly heat did not always correspond with fluctuations in the environmental conditions. Some cases improved at the same time as others deteriorated. In fact all the investigations except those on cases 1 and 7 were completed during May and June, when the weather was slowly becoming hotter and damper. In spite of the notorious fickleness of prickly heat - its tendency to inexplicable spontaneous remissions and relapses - it seems clear that it was relieved by increasing water intake and aggravated by increasing salt intake.

Prickly heat was not produced de novo in 1946 or 1947 by a short period of very high salt intake - for example 100 g. in three days - even though other symptoms developed which could be attributed to salt retention. Once a person had already had prickly heat, smaller quantities of salt seemed to cause a relapse.

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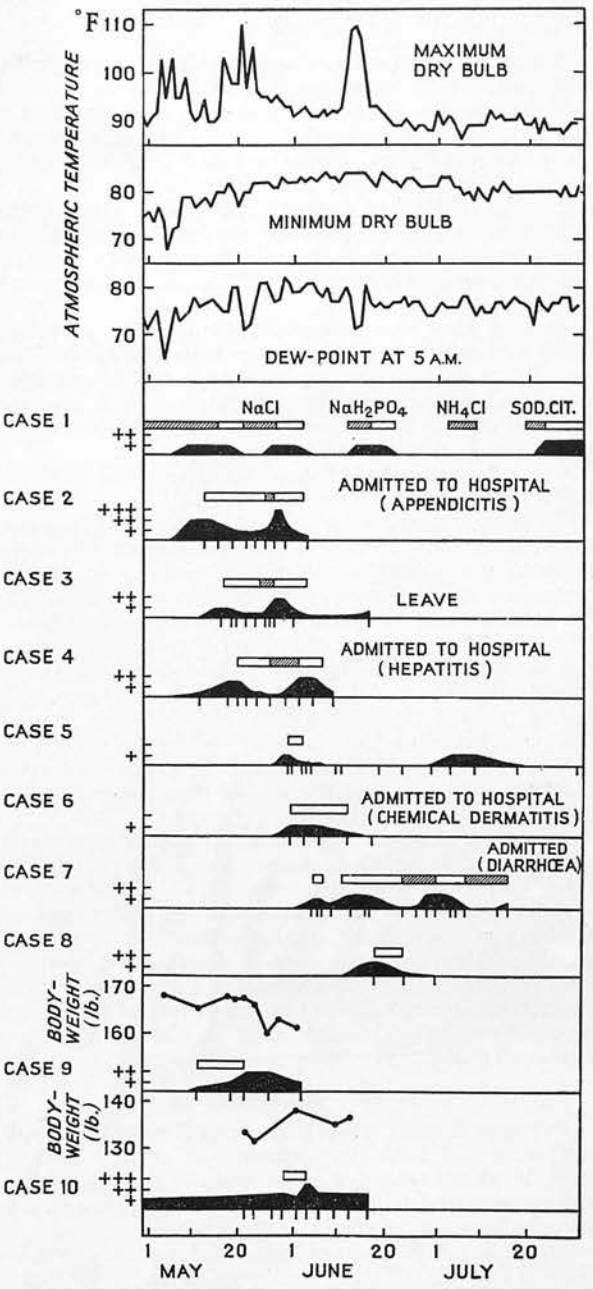

Alterations in intensity of prickly heat produced by alterations in intake of water and salt. The intensity of prickly heat is indicated by the height of the black areas and the plus signs. Periods of increased water intake are shown by empty rectangles. The shaded rectangles indicate the periods of increased intake of sodium chloride, except where otherwise indicated (case 1). Weight records are given for cases 9 and 10 (see text). The vertical bars below each base-line indicate the days on which the experimental subject was examined (case 1, being ■ the author, is considered to have been under continuous observation).

FIG. 8.

The author (case 1), after twice producing prickly heat in himself with extra salt and relieving it with extra water, took in successive periods sodium dihydrogen phosphate (0.2 gramme-moles), ammonium chloride (0.8 gramme-moles) and sodium citrate (0.4 gramme-moles). Ammonium chloride was not followed by prickly heat, but each sodium salt produced prickly heat. In 1946 ingestion of sodium dihydrogen phosphate was followed by prickly heat in one subject, who up till then had been free, but an increased water intake did not then relieve the prickly heat. Though the importance of the quantity of water needed was not then appreciated, it is interesting that the attack caused in case 1 by sodium citrate was not relieved by intensive water drinking for ten days.

An increased water intake failed to relieve spontaneous prickly heat in only two cases (9 and 10); in both of these there was a rapid deterioration. These were the only two cases in which alteration in water and salt intake was associated with large fluctuations of body-weight. Observations recorded in chapter 16 (Figure 10) showed that naturally occurring fluctuations in body-weight during the hot season were greater in the people who developed spontaneous prickly heat than in those who were apparently immune.

Other observations.

Fay and Susman (1945), in a naval vessel in tropical waters, found that the incidence of prickly heat was 60 per cent. in those taking a large additional ration of salt (18 people) and only 25 per cent. in those taking /

taking no extra salt or only a moderate amount (28 people).

D.T. Kay (1947,unpublished observations) examined several hundred R.A.F. personnel in India for prickly heat and inquired into their personal habits, work, and environment. There was a higher incidence of prickly heat among those taking additional salt (Table XIV).

TABLE XIV.

Incidence of prickly heat in relation to salt intake.[1]

Salt intake	Palam (Delhi)		Mauripur (Karachi)	
	1946		1947	
Salt in addition to that cooked with food	No.in group	Incidence of prickly heat (%)	No.in group	Incidence of prickly heat (%)
No salt	7	57	-	-
Salt as condiment only	43	84	25	36
Salt as condiment,plus 4 g. daily	90	91	30	43
Salt as condiment, plus 8-30 g. daily	132	92	26	100

[1] Unpublished observations of D.T.Kay.

M.L. Floyer (1947,unpublished observations) repeated at Cawnpore the experiment described here. The local additional salt ration of 10 g. daily was stopped and water intake increased by 15 pints daily. (In /

(In the hotter drier climate of Cawnpore it was easier to increase fluid intake than at Karachi.) After a week the severe prickly heat of the 4 subjects of the experiment had strikingly improved, whereas that of the 3 controls was stationary or worse. Subsequent observations were difficult to interpret, because the weather improved and co-operation in an attempt to restore the prickly heat was incomplete.

Discussion.

The therapeutic restriction of fluid in prickly heat has often been advised (Wehrle 1931, Ruge 1932, Blomfield 1943, Myers 1944, Napier 1946). Raine (1945) stated that "it has been established by experiment that the intake of sodium chloride bears no relation whatever to the incidence of prickly heat" but gave no evidence. These statements do not agree with our observations, which show that prickly heat can be made to relapse by increasing the intake of sodium salts and is usually relieved by reducing salt intake and increasing water intake. Many other factors are doubtless concerned, some of which will be discussed elsewhere, but clear-cut evidence is still wanting for all of them except the climatic factor.

The mechanism by which alterations in the metabolism of water and salt affect prickly heat is obscure. The serial experiments in case 1 suggest that the sodium ion is the important agent. The effective quantities of water and salt were so large, however, that sodium retention may not be the primary aetiological factor. The observation of McCance et al.(1944), that in human dehydration the intake of sodium chloride leads /

leads to an increased urinary excretion of potassium, illustrates the kind of secondary phenomenon which may have occurred during the experimental periods. On the other hand, there is evidence, summarised by Gregersen (1941), which suggests that the skin can store sodium chloride, and with less than enough water to dilute it to isotonicity. This might explain why an increased salt intake shows itself in some circumstances as a cutaneous lesion. Prickly heat is commonly assumed to be merely a local affection of the skin, but the evidence suggests that, like some other cutaneous syndromes, it may also be a manifestation on the surface of some general metabolic disturbance.

The turnover of salt and water in a hot climate may be very large, and may vary considerably from day to day, depending on the environment and on physical exertion. Thus short-term alterations in salt and water balances can easily take place and may be responsible for the spontaneous fluctuations in prickly heat already referred to. In the absence of a fuller understanding of the relative importance of the chloride and sodium ions it may not be easy to strike a balance between the prevention of chloride deficiency and the prevention of prickly heat.

Summary.

Prickly heat is relieved by increasing fluid intake and reducing salt intake. It can be made to relapse by increasing the intake of table-salt.

The evidence suggests that the sodium ion is the effective agent in causing prickly heat.

CHAPTER 16.

ENVIRONMENTAL AND INDIVIDUAL FACTORS IN THE AETIOLOGY OF PRICKLY HEAT.

Up till recent years there have been few planned investigations on the aetiology of prickly heat. The experimental work of the American Naval Medical Research Institute (summarized by Blum et al.,1945) showed that in humid environments prickly heat was produced in a few days in every subject exposed to a minimum effective temperature (Bedford,1946) of 88 deg.F. The lower minimum effective temperature of 78 deg.F. prevented prickly heat almost completely, even though for twelve hours of the day the subjects were exposed to an effective temperature of 90 deg.F. and also worked on a treadmill.

Field surveys of prickly heat by Fay and Susman (1945) on a naval vessel in tropical waters, and by Sulzberger and Emik (1946) at Guam, revealed no statistically demonstrable effect of environment. The latter authors, however, had the impression that prickly heat was worse in men working in laundries and kitchens and less common in those working in air-conditioned offices. Both investigations, however, failed to distinguish adequately between the incidence of prickly heat and its severity.

The complexity of the problem is illustrated by the experience of Ellis (1947) who found that on a battleship of the Eastern Fleet 26 per cent. of 479 ratings had severe prickly heat and 37 per cent. mild prickly heat /

heat, whereas on a cruiser a few cables away in the same port only 20 per cent. of 337 ratings had mild prickly heat. The average environmental conditions on the mess-decks of these ships were of the same order (effective temperature 82.7 deg.F. and 83.6 deg.F. respectively). There were other variables, such as the length of time recently spent at sea, but no clear reason why there should have been such a large difference between the two ships.

More recently extensive and important experimental studies have been carried out in America by Sulzberger and Zimmerman (1946), Sulzberger et al.(1950), Shelley et al.(1949) and Shelley and Horvath(1950a, b). They have studied various noxious agencies which can cause local prickly heat, with special reference to the hypothesis that the proximate cause is a sweat duct obstruction, to which many factors contribute. O'Brien (1950a,b.) has also closely studied the aetiology of poral closure.

This study is concerned principally with environmental and constitutional factors.

Observations on climatic factors.

At Karachi, India, the incidence and severity of prickly heat could be correlated with climatic factors since there were small but distinct meteorological differences between the various military camps and aerodromes in the area, some of which (as described in chapter 11, figure 3) were situated on the coast and some a few miles inland. In 1947, during the last week in June (the peak of the hot season) a survey was made of the incidence of prickly heat at three R.A.F. stations in the Karachi area - the Hospital and Mauripur (coastal) and Drigh Road (inland). The units at /

at Mauripur and Drigh Road were similar in type and in the work carried out. It was not possible for the whole survey to be conducted by the same person but there was an agreement among the observers as to what was to be called prickly heat. The results (Table XV) showed a considerable difference in incidence even after allowing for possible errors in classification. No analysis of the severity of prickly heat was made, but it was obvious to all who had the opportunity of seeing men from the different stations that it was greater at the coastal ones. This was confirmed by the repeated examination of a group of men from one of the inland stations and of the staff of the Hospital.

In 1946 prickly heat was more common and more severe than in 1947. No detailed survey was made in the former year, but the incidence of prickly heat at the coastal stations was probably greater than 90 per cent. and at the inland stations less than 50 per cent. Also, of the 35 cases that required to be admitted to hospital on account of this condition, 27 were from stations near the coast, although there were approximately the same numbers at risk at the coastal and inland stations.

The data from both years therefore show that prickly heat was both more common and more severe at the coastal stations, and this can be correlated with the higher minimum temperature and humidity of the air at these stations as compared to those further inland. The increased severity in 1946 as compared with 1947 can also be correlated with a similar increase in minimum temperature and humidity in 1946 over 1947. In each case a difference of a few degrees F. seemed to make a great difference. /

TABLE XV.

Unit	Strength	Number of men examined	Incidence of prickly heat per cent.
Hospital (Coastal)	160	150	74
Mauripur (Coastal)	1300	500	59
Drigh Road (Inland)	1300	300	32

Incidence of prickly heat in coastal and inland units, end of June, 1947.

difference. The meteorological data, which were discussed in chapter 11, show that for both comparisons, between coastal and inland camps, and between 1946 and 1947, the higher maximum temperature was associated with the lower incidence of prickly heat. The importance of the minimum temperature for prickly heat which was suggested experimentally seemed therefore to be confirmed by observation in the field.

In 1947, in mid-April, before there was any prickly heat, the minimum dry bulb temperature was about 72 deg.F. At the beginning of May, when prickly heat was beginning to occur, the minimum temperature was 74 to 76 deg.F. By the middle of May the minimum temperature had risen to about 79 deg.F., and 30 per cent.of the Hospital staff had prickly heat. In June, when the incidence of prickly heat was 74 per cent. (Table XV) the minimum temperature was still higher (Figure 9, page 241). The actual level of minimum environmental temperature at which prickly heat occurred in the field also agrees quite well with the experimental observations quoted above.

No reliable figures are available for the relative incidence and severity of prickly heat in hot dry and hot humid climates, but it seems certain, judging by personal communications from those with experience of both types of climate, that it is much greater in the latter. From meteorological data obtained at Karachi, India, in 1946 and 1947, and those provided by Morton (1944) for Hinaidi, Iraq, and by Ladell et al.(1944) for Shaiba, Iraq, it is possible to calculate approximately effective temperatures /

temperatures, using Bedford's (1946) charts. It appears that the effective temperature may be well below 78 deg.F. for a considerable part of the 24 hours in desert areas, whereas at Karachi, where the climate is of the hot humid type, it may never fall below 78 deg.F. for weeks on end during the summer. The greater incidence of prickly heat in hot humid areas is thus also in agreement with the experimental observations quoted above.

Other environmental and personal factors.

A fuller study of the relationship between prickly heat and environment was made on the "other ranks" of the staff of the R.A.F. Hospital at Karachi from April 1947, before prickly heat had begun to occur, until 25th June, when the investigation was terminated because the rate of change of personnel on the Unit rapidly increased. Only men who had been in the area since the beginning of April are included in the analysis, and this eliminated approximately 5 per cent. of the Unit.

With few exceptions the men were examined weekly or more frequently, usually while they were at work or playing games, when prickly heat was most likely to be evident, both subjectively and objectively. Records were made of the date of onset of prickly heat, of the appearance of the skin eruption and degree of discomfort complained of at the time of examination, and of the progress between examinations. An arbitrary grading was adopted according to the extent of the eruption and the discomfort present, bearing in mind that these two do not always run parallel.

At /

At the end of the period of observation the mildest cases in which the eruption had only been slight and the discomfort minimum, were allocated to the one plus group, those requiring admission to Hospital on account of prickly heat to the four plus group, and those with intermediate degrees of severity to the intermediate groups.

A large variety of trades and occupations were represented, from sedentary clerks to the more active nursing orderlies, cooks and motor transport drivers. For the purpose of the analysis the men were classified according to whether they did "night duty" or not, and according to the extent of their physical activity (Table XVI). "Day duty" involved working from approximately 8.30 a.m. to 4.30 p.m.; "night duty" from approximately 8.0 p.m. to 8.0 a.m., either on a "shift" basis, with duties overnight on two nights out of every five, or for a continuous period of two weeks once every six weeks or so. Night duty involved working fully clothed, that is with long trousers and sleeves rolled down as an anti-malarial precaution. Observation of each man's occupation and leisure-time pursuits made it possible to classify him also as "active" or "sedentary" in each of these respects.

At the beginning of the investigation each man was weighed, and classified as of "fair" or "dark" complexion, or, when it was difficult to decide, as "medium". He was also classified as "tanned" or "untanned", depending on whether the skin of the trunk was well sun-tanned or not. All the observations during the investigation were made by the author.

In /

TABLE XVI.

Group	No. of subjects	No. of subjects who developed prickly heat in the period			No. of subjects who failed to develop prickly heat	Incidence of prickly heat (per cent)
		Up to 14th May	15th May to 4th June	5th June to 25th June		
Daa	10	3	5	2	-	100
Das	36	11	10	10	5	86
Dss	31	8	10	3	10	68
Dh	5	4	-	1	-	100
Naa	5	3	1	-	1	80
Nas	42	12	17	8	5	88
Nh	11	2	5	2	2	82
Nr	10	3	2	3	2	80
Total	150	46	50	29	25	80

Analysis of the incidence and time of onset of prickly heat according to physical activity and nature of work.

The subjects were classified as follows:

Those who did "day duty" only	Active at work and leisure	Daa
	Active at work or leisure	Das
	Sedentary at work & leisure	Dss
Those who did "day duty" only, but worked in a hot atmosphere - (operating room assistants with duties in hot sterilising rooms)		Dh
Those who periodically did "night duty" (nursing orderlies, ward-masters and police)	Active at work and leisure	Naa
	Active at work or leisure	Nas
Those who did "night duty", but worked in a hot atmosphere (cooks)		Nh
Those who periodically did "night duty" but whose duties were "resting" or involved working in what amounted to air-conditioned surroundings		Nr

In order to illustrate the climatic environment in which the men were living data for a few days in June are recorded in Figure 9. Dry and wet bulb readings were made at two-hourly intervals on the verandah of one of the wards of the Hospital, using a sling psychrometer. Wind velocity was recorded at an airfield six miles away, and was of course much less inside the buildings although they were well ventilated. The diurnal variation, however, would have been in the same direction as at the airfield. The minimum temperatures, both dry and wet bulb, were reached between 4 a.m. and 8 a.m. The night was characterised by the highest relative humidity and the least wind, both factors which would interfere with the evaporation of sweat.

Analysis of Table XVI shows that there was no significant difference among the groups in the total incidence of prickly heat or in its onset by weeks, except between active and sedentary subdivisions of the "day duty" group (Daa,Das and Dss), the hazard being greater in the more active group. There was no statistically significant difference between the more active and less active subdivisions, whether of the "day duty" or "night duty" groups (Daa, Das and Naa, Nas). Although there appeared to be no significant difference between the "day duty" and "night duty" groups in incidence, there was a significant difference in severity of prickly heat when it did occur (Table XVII). This supported a strong clinical impression that those doing night duty suffered more severely. Further, the severity of prickly heat was significantly greater in active than sedentary groups, both by day and by night.

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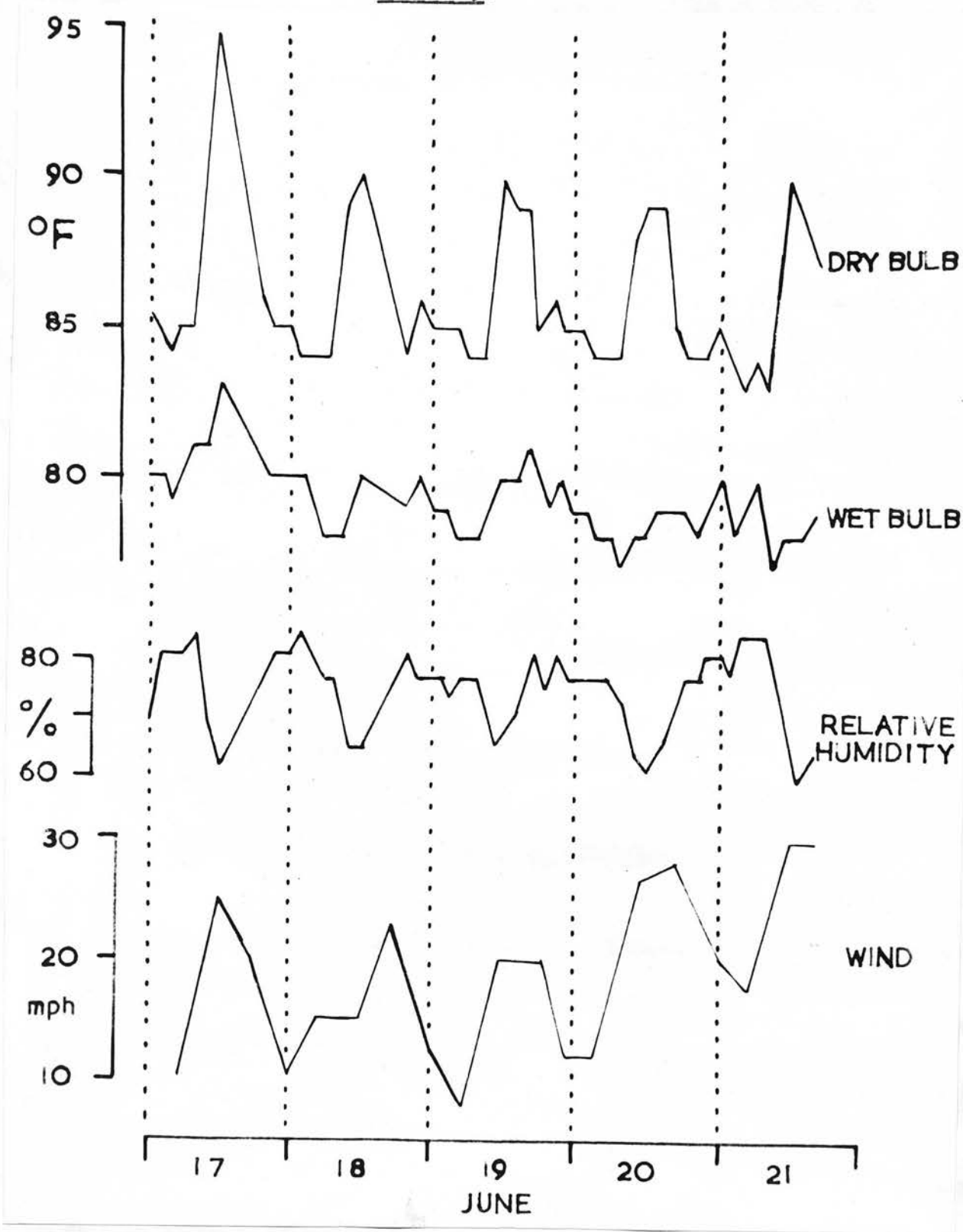
FIG. 9.



Diurnal variation in environmental conditions (Karachi, June 1947).

The vertical lines indicate midnight. Dry and wet bulb readings were made at two-hourly intervals on the verandah of one of the wards of the Hospital. Wind velocity was recorded at an airfield six miles away.

TABLE XVII.

Group	No. of subjects in each grade					Average severity of the cases of prickly heat (in plusses)
	Severity of prickly heat					
	Nil	+	++	+++	++++	
Daa	0	0	9	1	0	2.1
Das	5	12	13	5	1	1.8
Dss	10	11	10	0	0	1.5
Dh	0	2	3	0	0	1.6
Naa	1	0	2	1	1	2.8
Nas	5	7	16	9	5	2.3
Nh	2	3	6	0	0	1.7
Nr	2	7	1	0	0	1.1
Total	25	42	60	16	7	1.9

Analysis of the severity of prickly heat according to physical activity and nature of work.
For abbreviations see Table XVI.

The hot surroundings of the cooks and operating room assistants (Nh and Dh) did not appear to constitute an additional hazard. This was surprising, and was perhaps due to the clothing worn. The operating room assistants spent a large part of the day in the hot and humid sterilising room but during this time they frequently wore only shorts, or, in addition, a loose-fitting operating gown. The cooks spent a considerable part of their time in the vicinity of hot ovens, and wore shirts with long sleeves and long trousers all the time (the majority of the rest of the Unit wore short sleeves and short trousers all day). Their clothes, however, were made of a white material, very much superior to the khaki drill worn by all other personnel, and were not starched. The absorptive and evaporative qualities of this material were probably superior to those of starched khaki drill. In the middle of July it was interesting to notice the onset of prickly heat in one cook and the marked exacerbation in several others, within a few days of the substitution of khaki drill for the white clothes. The significance of different fabrics in relation to heat stress in the tropics has recently been discussed by Weiner (1947).

Search was made for further individual and environmental factors which might be concerned in the aetiology of prickly heat.

Complexion and weight.

The relation between complexion and prickly heat has frequently been discussed in the literature, and recently Master (1945) stated that fair and red-skinned people are particularly prone. Sulzberger and Emik (1946) felt /

felt that prickly heat was worse in the fair-skinned, and that obesity predisposed to it, but this conclusion was not supported by analysis of their data. At Karachi in the middle of July, of those who were still free from prickly heat, 9 were fair, 3 medium, and 4 dark. Of those who had spent more than one summer in India and had never had prickly heat (see under "constitutional tendency"), 6 were fair, 2 medium, and 3 dark. Thus a fair complexion seemed to reduce the susceptibility to prickly heat. Further, only one person who was both dark and "heavy" escaped altogether, and he was of a noticeably sedentary disposition even for those in the sedentary group.

Analysis of the relationship between complexion and weight and prickly heat was complicated by a difference between the "day duty" and "night duty" groups. Table XVIII suggests that in the "day duty" group (Das) there was a direct relationship between weight and prickly heat (the hazard being greater in the heavier), but that complexion was irrelevant. Table XIX suggests, however, that in the "night duty" group (Nas) weight was irrelevant but complexion might possibly be important (dark complexion being the greater hazard). Similar effects were apparent when the onset of prickly heat by weeks (Table XVI) was analysed according to weight and complexion. Absolute weight and "obesity" (i.e. weight in relation to body surface), are not strictly comparable, but the differences between Tables XVIII and XIX were not due to the relative underweight or overweight of a few individuals.

Sun-tanning /

TABLE XVIII.

		No. of subjects in each grade				
	Severity of prickly heat	Nil	+	++	+++	++++
Weight	Up to 129 lbs.	2	3	3	0	0
	130 - 139 lbs.	2	3	2	1	0
	140 - 149 lbs.	0	1	2	1	0
	Over 149 lbs.	0	1	4	2	1
	Unknown	0	1	0	1	0
Complexion	Fair	3	9		4	
	Dark	1	11		2	

Relationship between incidence and severity of prickly heat and weight and complexion in day duty group (Das).

TABLE XIX.

		No. of subjects in each grade				
	Severity of prickly heat	Nil	+	++	+++	++++
Weight	Up to 129 lbs.	1	1	8	1	0
	130-139 lbs.	0	2	1	3	1
	140-149 lbs.	1	2	2	2	1
	Over 149 lbs.	2	0	3	0	1
	Unknown	0	0	0	1	1
Complexion	Fair	4	8		4	
	Dark	0	11		7	

Relationship between incidence and severity of prickly heat and weight and complexion in night duty group (Nas).

Sun-tanning.

If complexion has an effect which depends on whether work is done by day or by night other factors relating to the skin must be considered, such as sun-tanning of the trunk, about the protective value of which there has been much controversy. Table XX gives an analysis of the incidence and severity of prickly heat in two groups of comparable physical habits (Das and Nas) set out in order to discover any possible effect of sun-tanning. In the untanned there was no difference in the incidence or severity between the "day duty" and "night duty" groups, or between the fair and dark groups, except possibly for an increased severity in dark people working at night. Tanning, however, appeared consistently to increase the severity of prickly heat, an effect more marked in the fair than in the dark, and in the "day duty" than in the "night duty" group.

If these conclusions are valid (and the numbers are too small for further analysis) it may be that the failure of the "day duty" group to show a relationship between complexion and prickly heat was due to the effect of exposure to the sun (i.e. tanning) in aggravating prickly heat in the fair more than in the dark. Such an explanation would reconcile part of the difference between the groups analysed in Tables XVIII and XIX, and suggest that night work as such may have been more deleterious than was indicated in Table XVII. These conclusions, even if true for Karachi, may not apply to a desert climate where radiation effects differ from those in a humid climate.

Tanning of the skin, however, cannot be considered apart from activity

TABLE XX.

Group	Complexion	Fair				Dark			
	Severity of prickly heat	Number of subjects			Average severity per case	Number of subjects			Average severity per case
		Nil	+ to ++	+++ to ++++		Nil	+ to ++	+++ to ++++	
Das	Untanned	1	7	1	1.7	1	7	0	1.8
	Tanned	2	2	3	2.8	0	4	2	2.3
Nas	Untanned	3	7	3	1.9	0	6	4	2.5
	Tanned	1	1	1	2.5	0	5	3	2.5

Relationship between degree of sun-tanning and incidence and severity of prickly heat sub-divided by complexion and by nature of work.

For key to abbreviations see Table XVI

Observation showed that there were two types of men who became tanned, the highly active who played games in the sunlight, and the sedentary who devoted their leisure time to sun-bathing. The most active groups (Daa, Naa) showed an incidence of tanning double that of the less active groups (Das,Nas), while the most sedentary group (Dss) was intermediate. Analysis also suggested that tanning of the skin was associated with an earlier onset of prickly heat in the active than in the sedentary, a difference again more marked in the "day duty" group than in the "night duty" group.

Constitutional tendency.

An attempt was made to investigate any "constitutional tendency" influencing prickly heat by recording the incidence and severity in successive summers. This was done by questioning those who had already spent one or more summers in India, the severity being determined from the history and assessed according to the standards already described. Table XXI shows the difficulty in interpreting an investigation of this kind. In each group in 1947 (when there was an objective record) the incidence of prickly heat was normally distributed. In each group in each other year (when prickly heat was measured by recollection) the distribution was not normal. It is more likely that this can be explained by the unreliability of memory or by a misinterpretation of their statements, than by a freak distribution of the witnesses among differing climatic conditions in the two earlier years.

Objective evidence of a possible constitutional factor was obtained from the analysis of serial weight records made at intervals throughout the /

TABLE XXI.

		2-year group		3-year group		
		1946 h	1947 o	1945 h	1946 h	1947 o
Severity of prickly heat	Nil	33	12	7	7	5
	+ to ++	20	57	4	4	12
	+++ to ++++	28	12	7	7	1
Total number of subjects		81		18		

Incidence and severity of prickly heat in successive summers.

h = assessed in retrospect from histories.

o = assessed by observation.

the summer on ten individuals. The data, recorded in figure 10, show that spontaneous fluctuations in weight were apparently associated with a susceptibility to prickly heat. When large fluctuations occur over short periods of time alterations in water and salt balance are the most likely cause. It has been shown in chapter 15 that prickly heat can be modified by alteration of the water and salt intake, increased water intake (along with a reduced salt intake) tending to relieve the condition, and an increased salt intake to aggravate it.

Summary and conclusions.

Relatively small variations in climatic conditions appeared consistently to influence the incidence and severity of prickly heat. The important factors appeared to be the minimum air temperature and humidity - the higher these were the more common and the worse the prickly heat, both from year to year and from place to place in the same year. The lower incidence of prickly heat in desert as compared to humid areas may also depend on the lower minimum temperature and humidity of the desert.

A detailed investigation at Karachi of 150 men continuously under observation for three months during the summer showed how insecurely based were a number of commonly held beliefs. Analysis of the data illustrated the complexity of the interplay of factors which are supposed to influence the development of prickly heat. No simple comparison of any pair of contrasted characteristics provided a sound basis for a conclusion unless many other factors were also taken into consideration. When division was carried /

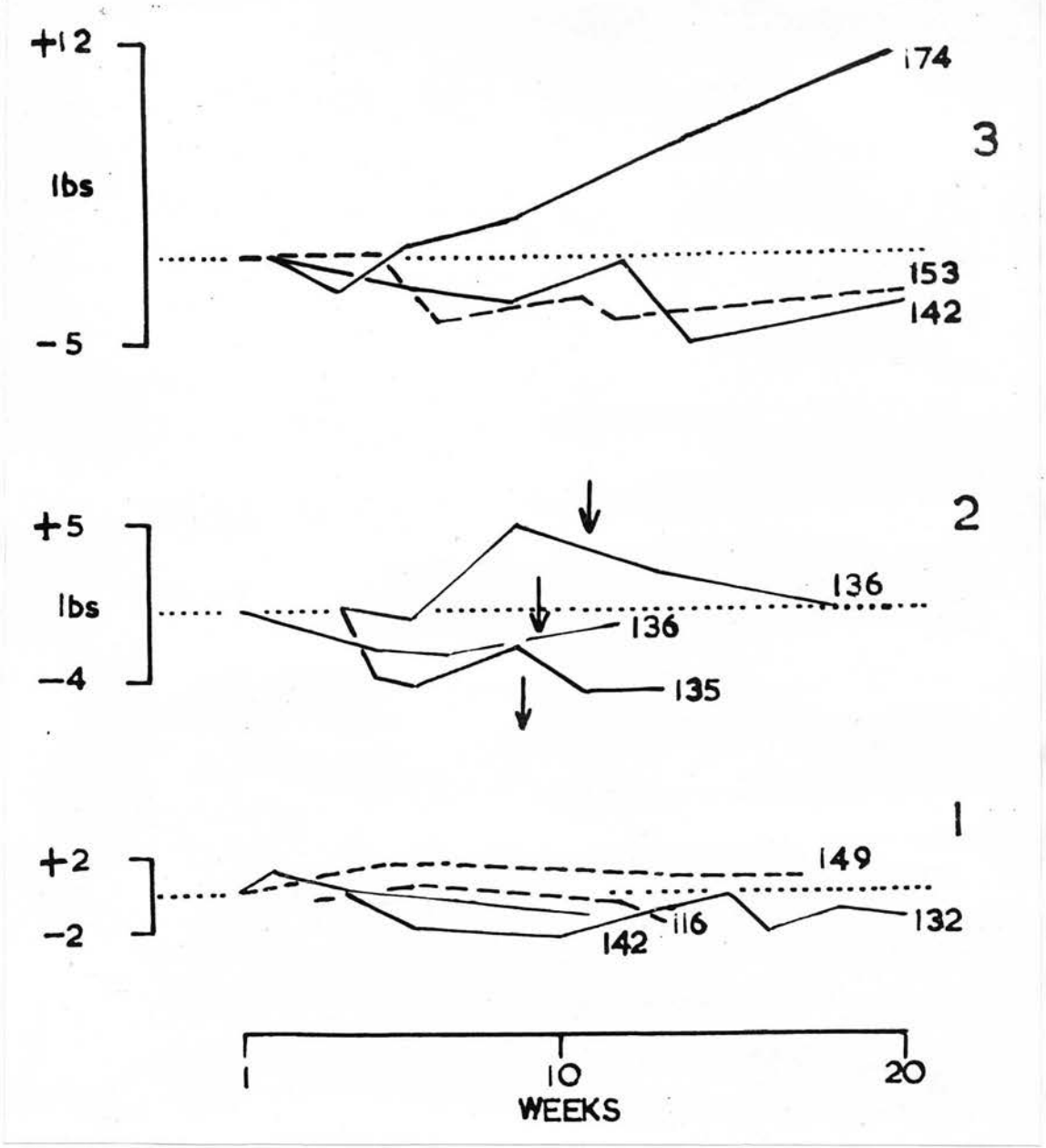


FIG. 10. Serial weight records and incidence of prickly heat.

Each point gives the deviation (in lbs.) of the observed weight from the initial weight. The last weight measurement for each subject is given (in lbs.).

Group 1. Subjects free from prickly heat during the whole of the observation period.

Group 2. Subjects who developed prickly heat during the summer, at the time marked by the arrow.

Group 3. Subjects who had developed prickly heat early, by the time of the first weight record.

carried on sufficiently far to make the sub-groups homogeneous the numbers were too small to be statistically valuable. It was also shown that recollected clinical histories were an unreliable source of evidence.

It is therefore not surprising that many heterogeneous and contradictory statements have accumulated in the literature on prickly heat. Two strong clinical impressions were confirmed, however, that prickly heat was worse in men whose duties included working overnight, and in the active as opposed to the sedentary.

It is probable that methods similar to the experimental approach of the American Naval Medical Research Institute (summarized by Blum et al. 1945), of Sulzberger and Shelley and their colleagues, and of that described in chapter 15, would be more successful in establishing the important environmental and individual factors in the aetiology of prickly heat.

CHAPTER 17.

CLIMATIC ENVIRONMENTAL FACTORS IN THE AETIOLOGY OF SKIN DISEASES.

Military service, especially in hot climates, is always associated with a large incidence of skin diseases, and in some theatres of war has proved a serious medical and administrative problem. It is not easy to distinguish the relative importance of the various possible causes, but at Karachi in 1946 and 1947 the opportunity arose of investigating the effect of environmental heat and humidity on the incidence of certain skin diseases.

CLINICAL MATERIAL.

The principal criterion for admission of cases of skin disease to hospital was their severity, and available beds in the hospital were increased in number (up to 150 for one period of several weeks) to serve the demand, although at the peak of the hot season the admission of some cases had to be postponed. Cases transferred from other areas have been omitted from the analysis. The hospital admission rate therefore provided a good basis for assessing the effect of environment at Karachi. As has been described in chapter 11, the military camps were situated along the /

the coast and at different distances from the sea (Figure 2, page 154), and meteorological data showed that the most humid area was the coastal strip, and the further inland the camp the lower the minimum temperature and the higher the maximum temperature. The incidence of skin diseases in the different camps thus provided another means for determining the effect of climatic environment. A third means was provided by comparing the incidence in 1946 with that in 1947, when the climatic conditions during the summer were not nearly so severe.

RESULTS.

Figure 11 shows that there was a marked seasonal variation in the admission rate for prickly heat, bullous impetigo and hydradenitis. All the cases occurred in the same period of the year, the height of the hot weather. The admission rate for fungus infections and "other pyogenic infections" of the skin showed only a small seasonal variation, but there was no clear variation of this type in the other skin diseases. Some climatic factor was therefore of considerable importance in the aetiology of the first group, of less importance in the second and apparently of no importance in the third. Figure 11 suggests that this factor was the minimum dry bulb temperature and humidity rather than the maximum temperature, since the latter lay between 89 and 95 deg.F. for the greater part of the year. Small differences of a few degrees seemed to be important when the minimum temperature was of the order of 80 deg.F.

Table XXII shows the incidence of skin diseases during the hot season /

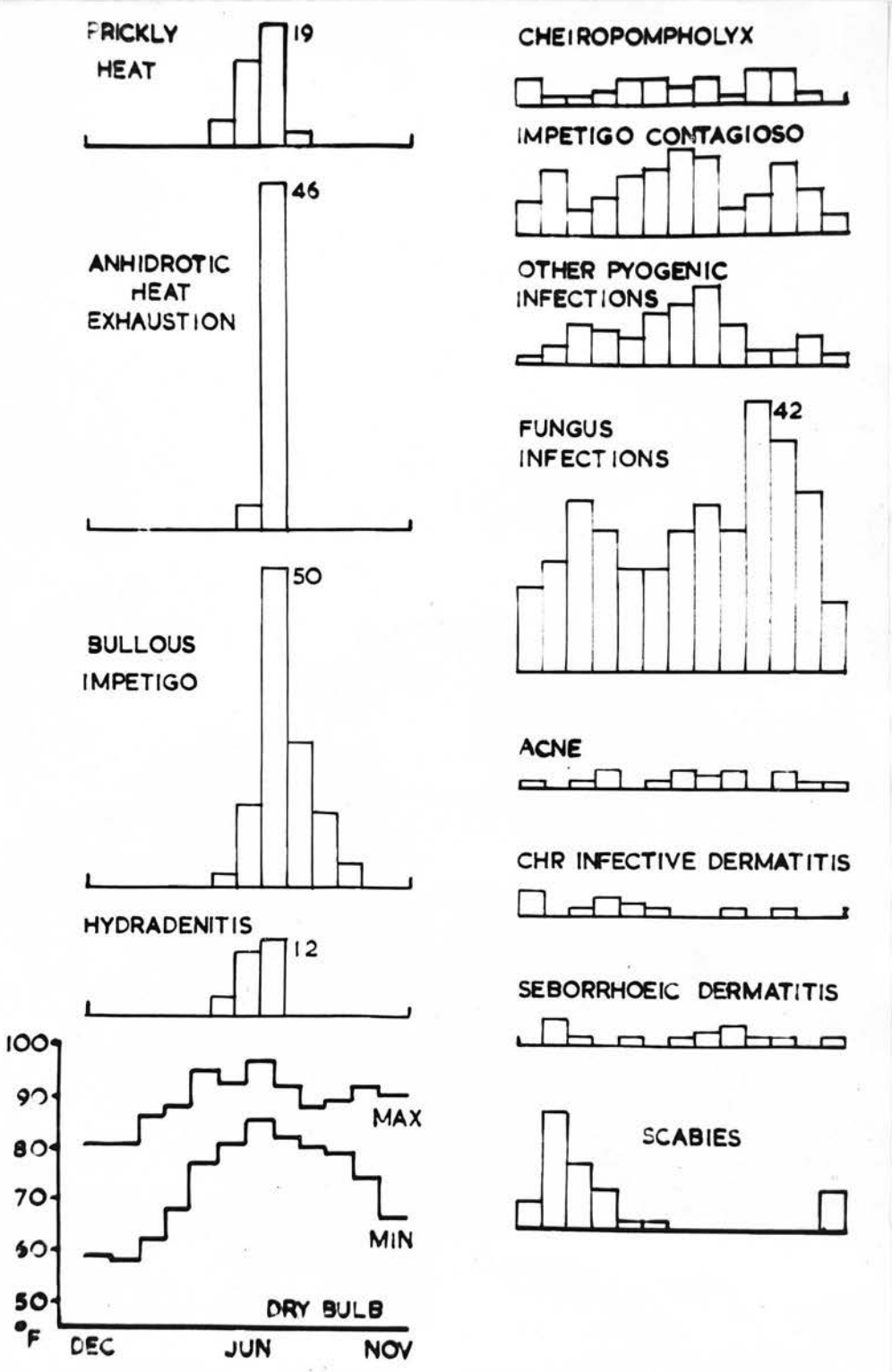


FIG. 11. Hospital admission rate for skin diseases, (Karachi, 1946) to show seasonal variation.

The incidence is shown in four-week periods from December 1945 to November 1946 (inclusive). The climatic data (obtained from Drigh Road) illustrate the environmental conditions of the Karachi area during this period. The wet bulb temperature ran parallel to the minimum dry bulb.

TABLE XXII.

Group	Service	ARMY		R.A.F.	
	Camp	Coastal	Inland	Coastal	Inland
	Strength	1100	1400	2250	1200
I	Prickly heat	12	6	8	0
	Anhidrotic heat exhaustion	26	3	8	4
	Hydradenitis	11	4	2	3
	Bullous impetigo	41	21	12	3
II	Impetigo contagiosa	17	14	7	2
	Other pyogenic infections	11	6	8	0
III	Acne	6	4	3	3
	Fungus infections	55	50	14	3

Hospital admission rate per 1000 for diseases of the skin during the hot season, 1946 (20th April to 4th October) subdivided by service and by camp.

The Army figures are likely to be more valuable than the R.A.F. for reasons discussed in the text.

season (April to October) subdivided according to camps. As already stated, the coastal camps had the higher minimum air temperature and humidity, and the higher incidence here of the first group of skin diseases supports the conclusion that they were particularly dependent on these climatic factors. Just as the incidence of the third group of skin diseases was independent of season so it was not affected by camp site. Factors other than climate are, of course, important in the causation of skin disease, as illustrated by the higher incidence in the Army than in the Royal Air Force, but coastal and inland camps could be compared since living and working conditions for units of the same branch of the Service were similar.

Diseases obviously dependent on climate.

Prickly heat. Only the most severe cases were admitted to the hospital. The real incidence was about one hundred times the admission rate, so great stress is not placed on the comparative data for admissions from the different camps. The actual incidence in one of the coastal camps was greater than 90 per cent. and in one of the inland camps less than 50 per cent.

Anhidrotic heat exhaustion may be considered as some measure of the incidence of severe prickly heat since, at Karachi, this invariably preceded the anhidrotic syndrome (chapter 11). Every case of this syndrome that occurred is known to have been recorded, so that the numerical data in Table XXII are exact, and correspond with the greater severity of the climatic conditions in the coastal area. A fuller discussion on the relation /

relation between climate and prickly heat has been made in chapter 16.

Bullous impetigo. A good description of the severe and extensive nature of this disease as it occurs in the tropics is given by D'Avanzo (1945). When it was found at Karachi that it responded dramatically to penicillin the number of cases needing admission to hospital in the latter part of the hot weather was reduced by the issue of penicillin cream to unit medical officers.

Hydradenitis. This disease also is seen in a much more severe and extensive form in the tropics than in temperate climates (Reiss,1943). It responds to parenteral penicillin, and all severe cases were admitted to hospital.

Combinations of prickly heat, bullous impetigo and hydradenitis in the same patient. Since the incidence of each of these conditions appears to be closely dependent on climate, combination of two or three of them might be expected to occur in the same patient, as they commonly did at Karachi. Six out of 25 cases of hydradenitis and 23 out of 103 cases of bullous impetigo were noted to have marked prickly heat, several cases of anhidrotic heat exhaustion had bullous impetigo when they were first seen, and in some of them it is known to have developed after the onset of anhidrosis. The association of prickly heat and hydradenitis was noticed by Reiss (1943), and of prickly heat and bullous impetigo by Bigham (1944), Myers (1944), D'Avanzo (1945) and Robertson (1945). Simons (1946) stated that bullous impetigo may be followed by hydradenitis.

D'Avanzo /

D'Avanzo (1945) also noted that the incidence of bullous impetigo bore no relation to that of impetigo contagiosa and at Karachi only the former was related to climate. O'Brien (1950a) has recently demonstrated a histological, and possibly an aetiological, connection between prickly heat and bullous impetigo.

Fungus infections. These were undoubtedly more common during the hot season, and the unchanged admission rate probably did not mean that the actual incidence was stationary. The peak incidence of admissions after the hottest part of the season is accounted for in part by the larger number of beds that became available for the treatment of these conditions, and in part by the higher incidence of chemical dermatitis and eczematisation that often followed the treatment of such cases on units and necessitated subsequent admission to hospital.

Other skin diseases.

Pyogenic infections of the skin and its appendages (folliculitis, furunculosis and sycosis barbae) occurred throughout the whole year, but showed a slightly higher incidence in the hot season. It was perhaps surprising that the seasonal incidence was not more marked. Impetigo contagiosa was more resistant to treatment during the hot season and this may have accounted for the slight increase in numbers admitted. Acne did not show the expected increase in incidence during the hot season, but there is no doubt that the worst cases were seen at this time, and of the 12 cases returned to the United Kingdom for this condition during the year /

year under review, 6 occurred in June and July. Scabies occurred in two "epidemics" which had no direct relation to climate. All but three of the cases between December and April occurred at the R.A.F. Station responsible for air-trooping between the United Kingdom and India, and the three other men had recently arrived from Rangoon. There were no further cases after air-trooping ceased. The small group in November was also associated with the arrival of three men by air from the United Kingdom, and all six were from the same unit. A similar experience is recorded by Myers (1944).

OBSERVATIONS IN 1947.

During 1947 the opportunity arose of observing the incidence of skin diseases both at the hospital and in individual units in the area. Cases of bullous impetigo and hydradenitis were rare, prickly heat much less common and less severe, and there were never more than twenty to thirty patients in the skin wards, even at the height of the hot weather. The summer was much less uncomfortable than in 1946, although the maximum dry bulb temperature was frequently higher. The minimum temperature and humidity, however, were lower. Detailed meteorological data are given in chapter 11.

DISCUSSION.

The survey revealed a definite effect of temperature differences, but only in some skin diseases did they appear to play a crucial aetiological role, when the minimum temperature and humidity were apparently important. In 1946 the minimum temperature was over 78 deg.F. for the four hot months, and in the latter half of June was continuously above the temperature at which sweating is bound to occur even in a naked man at rest. Also, according to Mole (1948), the higher the humidity of the air the higher the humidity of the skin and, as each of these climatic factors will increase the humidity of the skin surface, it may be an alteration in this property which predisposes to prickly heat, bullous impetigo and hydradenitis. If so, these conditions should be much less common in dry desert climates, even if the dry bulb temperature is much higher. This is true of prickly heat and is also borne out by the fact that all the published reports on the other two diseases come from humid climates, none from the desert.

While there is obviously a close relationship between prickly heat, hydradenitis and bullous impetigo, the nature of this relationship is still obscure, and it is premature, if not confusing, to include the two last named among the "forms of prickly heat" described by Blomfield (1943) and quoted by Manson-Bahr (1945), in spite of the recent observations of O'Brien (1950a).

The environmental factor in fungus infections seemed to be of minor importance, but this may be misleading, for reasons stated earlier. Also, it /

it is in this group that the inevitable deficiencies of such data are probably most significant, as only a complete field survey could have revealed the true incidence. When severity is the principal criterion for admission to hospital, the rate will obviously depend to some extent on the ability of unit medical officers to treat early cases successfully, bearing in mind that their enthusiasm may sometimes actually increase the numbers eventually requiring admission. However, there was close co-operation with all the unit Medical Officers, and it is believed that no major errors have occurred as a result of relying on hospital data as a measure of disease incidence.

SUMMARY.

At Karachi, climate was a major factor in the causation of prickly heat, bullous impetigo, and hydradenitis, and of much less importance in the causation of other pyogenic and fungus infections of the skin. The important climatic factors appeared to be the minimum dry bulb temperature and humidity, not the maximum dry bulb temperature. Small differences of a few degrees F. seemed to be important when the minimum temperature was of the order of 80 deg.F. Possible ways in which these factors are effective are discussed.

SUMMARY

Following a review of the physiological principles involved in the regulation of body temperature and of the various ways in which the body is known to react when it is exposed to abnormal degrees of environmental heat, a "working" classification has been proposed in an attempt to clarify these heat effects syndromes. The terminology used was based on names hallowed by tradition, but modified in such a way as to illustrate the aetiology and principal clinical features of the syndromes. It was not claimed that the classification should be the definitive one, because of certain deficiencies in knowledge.

Then, following a consideration of the different types of climate in which heat effects syndromes are known to occur, the expected distribution of thes syndromes according to climatic conditions was deduced. This hypothesis was shown to be correct by personal experience and a study of the reports of the experience of other observers.

A detailed study of the syndromes illustrated the importance of the different factors contributing to "climate", but also demonstrated the difficulty in assessing their relative contribution. This was sometimes increased by the fact that environmental conditions cannot always be assessed from observations made by conventional methods, since these may be very remote from actual living and working conditions. Whilst the relationship between dry bulb temperature and heat stroke

is fairly obvious it has been clearly demonstrated that the minimum dry bulb and the wet bulb temperatures are also very important factors in the aetiology of some heat effects syndromes, although their exact contribution in particular syndromes has been difficult to assess from the data available. This was well illustrated in the discussion on anhidrotic heat exhaustion (Chapter 11), and in particular in the interpretation of the significance of the changes in the minimum dry bulb and wet bulb temperatures associated with the abrupt cessation of the epidemic of this syndrome at Karachi in 1946 (figure 6). There is no doubt, however, that the wet-bulb temperature, long known to have a great influence on comfort sensation and ability to work in hot environments, makes a definite contribution to the aetiology of some heat effects syndromes.

It has also been shown that certain climatic factors, including the wet-bulb temperatures, are important in the aetiology not only of prickly heat (a condition of much greater importance than has hitherto been appreciated) but also of other skin diseases.

Important deficiences in knowledge have also been revealed and suggestions made for their remedy, but it has been pointed out that experiments conducted in artificial environments have a limited application, and that further studies in the field are also necessary to clarify the outstanding problems.

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