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The effect of environmental temperature on the metabolism and nutrition of burned patients

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The nutrition of patients with extensive burns usually requires daily intakes of fats, proteins and carbohydrates with a total calorific value in excess of 4000 kcal together with supranormal amounts of water and various ions, mainly sodium. These calorie requirements by a patient confined to bed are approximately those required by a normal adult male performing hard manual work. Recognition of the reasons for these large calorie requirements arose from the studies of Caldwell, Osterholm, Sower & Moyer (1959) with burned rats, who showed that these animals had a high rate of evaporation of water from the surface of the burned area. As the evaporation of water is an energy-consuming process, requiring 580 kcal/l, a burned patient losing 86 ml of water/h by evaporation from the burned surface requires 1200 kcal of energy/d for this process alone.

Precise measurements of the rate of evaporation of water from the burned surface have been made by Harrison, Moncrief, Duckett & Mason (1964), Roe & Kinney (1964), Barr, Birke, Liljedahl & Plantin (1968) and Zawacki, Spitzer, Mason & Johns (1970) using scales with a sensitivity of about 2 g. A change in body-weight over a period of 30 min indicated the total water loss from the body. In patients with burns of moderate severity between one-quarter and one-third of this water loss is from the lungs, the remainder from the burned area. In patients with very extensive burns the respiratory loss of water is only a small proportion of the total loss. Average values for the rate of water loss by evaporation from numerous burned patients with burns of different severity are shown in Table 1. The energy requirements for this evaporation of water are also shown and may be compared with the evaporative water loss in a normal person (mainly via the respiratory tract) and the energy production by a normal 70 kg male in the basal and moderately active states.

At the time of these increased requirements for calories for the evaporation of water, the patients showed substantially increased metabolic rates (see Davies & Liljedahl, 1971). In patients with burns of about 25% of the body surface the metabolic rate was about 50% above normal during the first 2 weeks after burning

Table 1. *The rate of water loss by evaporation from patients with burns of different severity and the energy required for this evaporation*

(A normal male weighing 70 kg evaporates approximately 0·85 l water/d, requiring 490 kcal energy. The basal heat production of such a male is approximately 1700 kcal/d and, with moderate activity, approximately 2700 kcal/d)

Area of third degree burn (%)	Evaporative loss of water (l/d)	Energy required to evaporate the lost water (kcal)
20–40	1–2	580–1160
40–60	3–4	1740–2320
60–90	5–7	2900–4060

and then slowly declined towards the normal value. When the burned area covered approximately 50% of the body surface the metabolic rate increased transiently to more than 100% above normal and was more than 70% above normal for at least 7 d.

The peak rate of energy production occurred about 7 d after burning. Secondary increases in metabolic rate were observed after extensive excision and grafting operations which coincided with, and may have been the result of, the increased rate of evaporation of water from the combined area of the burn and autograft skin donor sites.

A factor which considerably modifies the metabolic rate is the temperature of the environment surrounding the patient. An extensive comparative study has been made of the effects of treating burned patients in either a warm, dry environment (air temperature 32°, relative humidity 20–30%) or in a cooler, moister environment (air temperature 22°, relative humidity 30–70%). Many results from these studies have been described by Barr *et al.* (1968), Davies, Liljedahl & Birke (1969), Davies & Liljedahl (1970, 1971). Results from some of these studies are illustrated in Fig. 1. Both the average metabolic rates and the average rates of evaporation of water were calculated from two groups of six adult patients with burns of about 30% of the body surface (range 25–35%). One group of patients was treated in the warm, dry environment and the other in the cooler, moister environment. In the cooler environment the average metabolic rates were significantly greater than found in the patients treated in the warmer environment. In contrast, the rate of loss of water by evaporation from the burned surface was not significantly altered by the relatively low or high humidity of the ambient air maintained at the different temperatures. The change in metabolic rate must therefore be due to a reduction in heat loss by radiation, convection and conduction and a corresponding saving in calorie requirements.

The rate of evaporation of water from the burned surface can be reduced by applying autograft or cadaver homograft skin to the burned area (Lamke, Körlof, Liljedahl & Nylén, 1971). The skin is applied to the burned area after pieces of eschar have floated free during the thrice-weekly soaking of the patient in a warm saline bath. Precise body-weight measurements have shown that this treatment significantly reduced the rate of evaporation of water from the burned surface
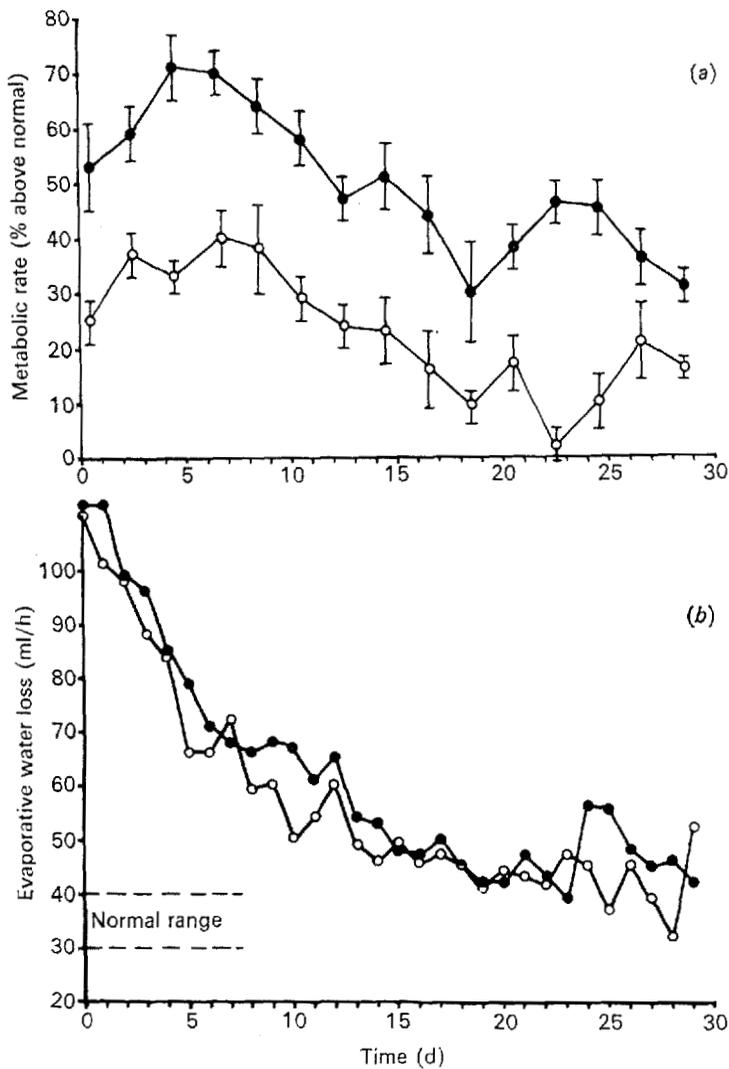
Fig. 1. *a*, Average metabolic rates (the vertical bars indicate the standard errors) and *b*, average rates of evaporative water loss from two groups of six adult patients with burns of approximately 30% of the body surface. One group of patients was treated in the warm environment (○) and the other in the cool environment (●) for at least 4 weeks after burning.

and oxygen consumption studies revealed a corresponding reduction in calorie production.

The optimum environmental temperature to reduce both the elevated metabolic rate and the body heat loss by radiation, convection and conduction has not yet been determined, although it seems probable that this temperature will be just below that at which the patients unburned skin starts to sweat. This threshold temperature will no doubt vary between patients of different ages and sex and during the healing process of the burned area; it probably lies between 33 and 36°. One of the diffi-

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culties of estimating this optimal environmental temperature is the considerable
variation of body temperature of burned patients irrespective of the environmental
temperature. Average body temperatures at 07.00 hours each day in the two groups
of six patients treated in the different environmental temperatures (Fig. 2) showed
substantially raised body temperatures during the first week after burning, with
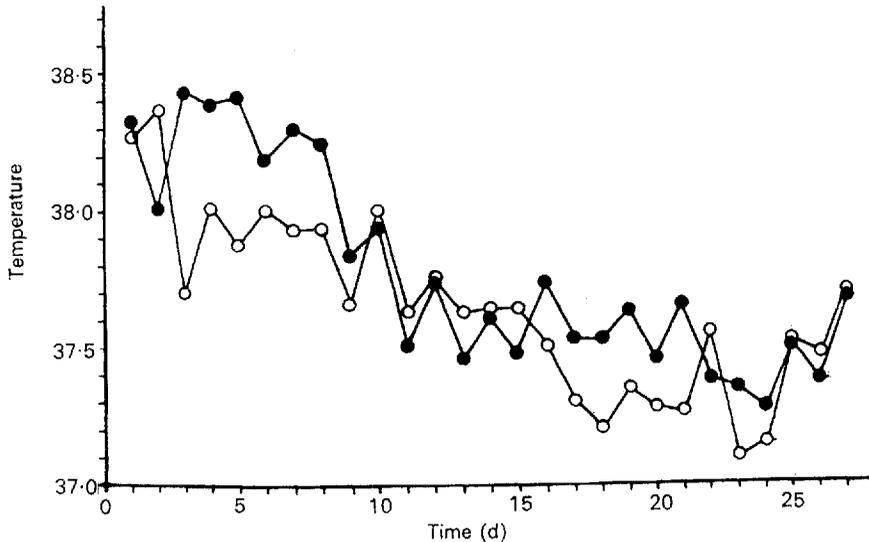

Fig. 2.   Average morning body temperatures measured at the time of the oxygen consumption
measurements from two groups of six adult patients with burns of approximately 30% of the body
surface. One group of patients was treated in the warm environment (○) and the other in the cool
environment (●) for at least 4 weeks after burning.

evening temperatures averaging 0·5 to 1·0° higher than the morning temperatures.
The use of body temperature as an index of the optimal value for the environmental
temperature may therefore not be very precise.

These raised body temperatures, of course, are a reflection of the raised metabolic
rates. In all patients, however, the metabolic rate was greater than indicated by the
body temperature, assuming that a 1° rise in body temperature is associated with a
12·5% increase in metabolic rate. In most patients the metabolic rate was more than
20% greater than suggested by the raised body temperature measurements for at
least 10 d after burning. A similar increase in metabolic rate in spite of any increase
in body temperature has been observed in patients with forms of injury other than
burns treated in a very similar warm environment (Cuthbertson & Tilstone, 1968).

As described previously (Davies & Liljedahl, 1970), it is important that the ambient
air should have a temperature above that of the burned skin, which is frequently
between 28 and 29°, so that a net transfer of calories from the environment to the
burned tissues is possible. The ambient air temperature will be lower than that of the
unburned skin which will be about 35°. Recent studies in two burned patients with
very extensive burns covering more than 75% of the body surface strongly suggest
that some calorie transfer from the environment to the patient occurs. In the results
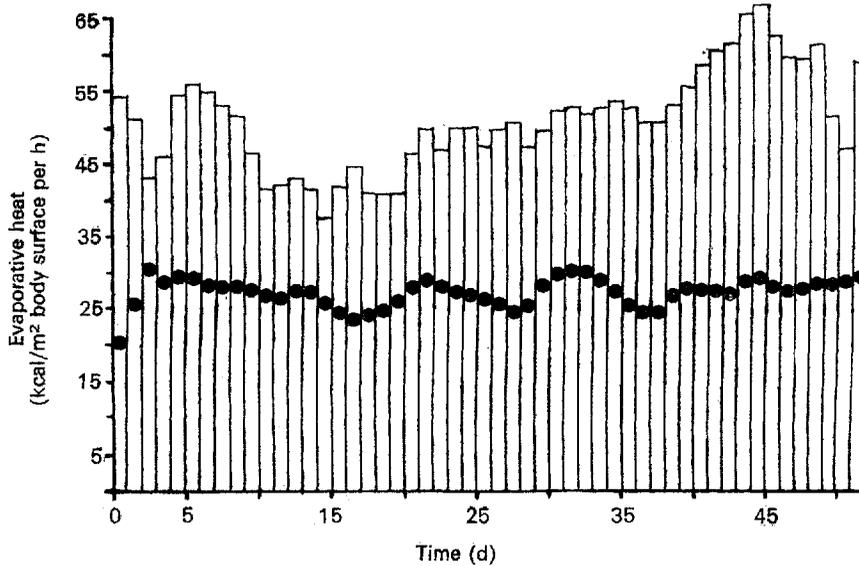shown in Fig. 3, the energy required for the evaporation of the measured water loss

Fig. 3. The quantity of heat required for the evaporation of the measured quantities of water lost from the burned surface (the columns). The filled circles (●) denote the quantity of heat produced above the expected basal value calculated from estimates of oxygen consumption. The burned area covered 80% of the body surface, 72% of which was full thickness skin loss. The patient was treated in the warm environment.

together with that required for other metabolic purposes was greater than the heat production as measured by oxygen uptake studies. As might be expected, this effect of heat transfer from the ambient air to the burned tissues is most marked in the patients with the most extensive burns. Firm evidence of this heat transfer has, in fact, only been obtained in patients with burns covering more than 40% of the body surface.

Another study has shown that body protein as well as fat is catabolized at a higher rate to provide the increased calories liberated during the period of raised metabolic rate (Davies & Liljedahl, 1970). Although in both the warm and cool environments all the patients showed increased rates of urinary excretion of nitrogenous compounds, there was less nitrogen excreted in the urine of the patients treated in the warm environment than found in the urine from the patients treated in the cool environment. This general body protein catabolism also involved the plasma proteins, since both plasma albumin and γ-G-globulin were catabolized at about twice the expected normal rates in the patients treated in the cool environment (Davies *et al.* 1969). In the warm environment approximately normal rates of catabolism have been observed in patients with burns of approximately 30% of the body surface. In patients with more extensive burns greater rates of plasma protein catabolism have been observed in both groups of patients but, again, the rate of catabolism was always greater in the cooler than in the warmer environment.

The amounts of protein catabolized by these patients in excess of the amounts catabolized by normal persons receiving an adequate diet liberated only a few hundred

kcal of energy. The patients with burns of moderate severity derived about 300 kcal/d and those with the most extensive burns about 600 kcal/d from the extra protein catabolism. This extra catabolism of body protein may not be primarily orientated towards the provision of energy. It may only be a by-product of a catabolic process providing essential intermediates for the functioning of the tricarboxylic acid cycle. Most of these intermediates are normally derived from carbohydrate metabolism. The available evidence in patients with burns however suggests that the normal body carbohydrate stores are rapidly depleted after burning, and that in the absence of a substantial carbohydrate intake, gluconeogenesis provides some of the essential intermediates for the energy-producing mechanisms.

The remaining calorie requirements not provided by carbohydrate and protein are derived from the fat reserves of the body. In patients with very extensive burns these fat stores may be depleted at a fairly rapid rate, since the greatest requirements for energy usually occur at a time when the patient is anorexic and unable to consume orally sufficient high calorie diet to satisfy the calorie requirements. In these patients the intravenous administration of calories may be a life-saving procedure. During the last 2 years the lives of three adult patients with burns of between 75 and 85% of the body surface have been saved. During their stay of 3–4 months in hospital these patients each received between 56 and 72 l of 20% fat emulsion (Intralipid;
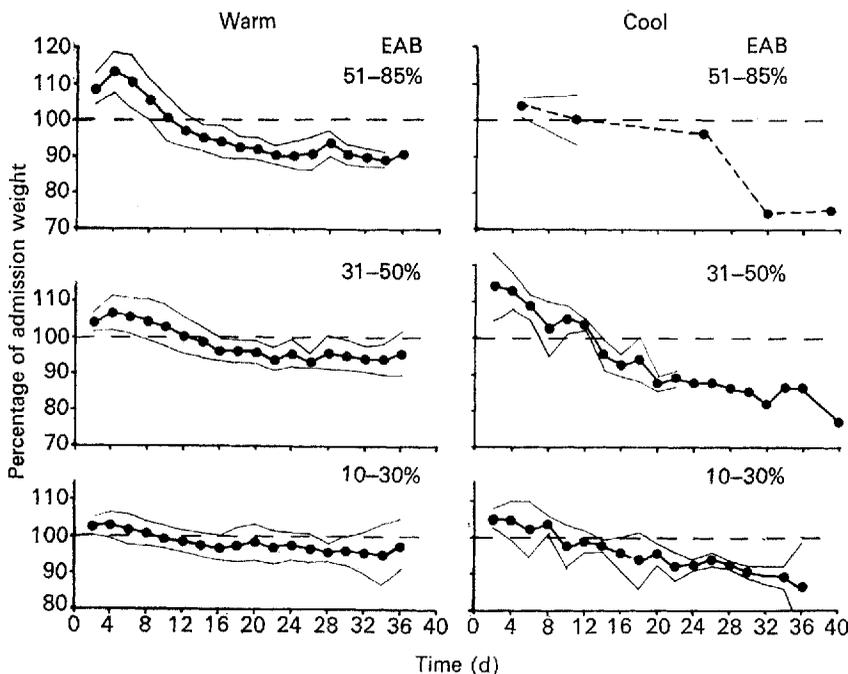

Fig. 4. Measurements of body-weight averaged over 2-d periods expressed as percentage of the weight on admission to hospital. The solid lines above and below the filled circles indicate the standard deviations. The patients have been grouped according to the temperature of the environment and the severity of the burn. EAB, estimated area of the burn as % of the total body surface. This figure has previously appeared in Davies & Liljedahl (1970), and is reproduced with the permission of the publishers (J. & A. Churchill).

Vitrum AB, Stockholm, Sweden), which provided between 56 000 and 72 000 kcal of energy in addition to that derived from as much of the enriched oral diet as the patient could consume each day. No complications were observed following the intravenous infusions of the large volumes of Intralipid. In addition to the fat emulsion the patients were also given intravenously amino acid solutions, human plasma albumin solution, concentrated carbohydrate solutions and insulin.

The success of the treatment of these patients may be gauged, firstly, by the minimal body-weight changes observed during their stay in hospital (Fig. 4). Each patient lost less than 10% of their admission body-weight while in hospital. Similar reduced losses of body-weight have been observed in patients with less extensive burns when they were nursed in the warm, dry environment compared with the greater losses of body-weight shown by the patients treated in the cooler, moister environment (Davies *et al.* 1969). Secondly, these patients treated in the warm, dry environment had a markedly improved clinical condition compared with that of patients treated in the cooler environment. Although this impression of clinical well-being is hard to quantify, it probably reflects the absence of a 'stress reaction' which is latent in all patients soon after severe injury. This reaction is masked by adequate treatment and only develops into a recognizable form with inadequate or inappropriate treatment. One effect observed in patients showing the 'stress reaction' is a renal retention of sodium. In patients with burns who were probably treated in a relatively cool environment a pattern of sodium retention during the 1st week after burning has been described by Cope & Moore (1947), Bull & England (1954) and Davies (1967). In contrast, the recent studies in patients treated in a warm, dry environment show that there is very little or no renal retention of sodium by those who show little clinical evidence of a 'stress reaction'. In a comparative study of thirty-six adult patients with burns of between 20 and 60% of the body surface, eighteen of whom were treated in the warm environment and the remainder in the cooler environment, there was a significant difference in the rates of renal excretion of sodium between the two groups. Although the amounts of sodium (in m-equiv./kg body-weight per 1% of burned area) given to the patients during the first 48 h after burning were almost identical, and the subsequent daily sodium intakes always ranged between 150 and 250 m-equiv./d, the patients treated in the cooler environment always excreted less than 40 m-equiv. of sodium in their daily urine output for at least 1 d during the period between 3 and 7 d after burning. Most of the patients excreted less than 20 m-equiv. in 1 d. No such retention of sodium was observed in the patients treated in the warmer environment, who always excreted more than 40 m-equiv. sodium/d and most of the patients excreted more than 100 m-equiv. sodium/d.

In conclusion, these studies suggest that the greatly increased energy requirements of patients with extensive burns may be reduced by the following measures.

(1) Treatment of the patient in a warm dry environment.

(2) Use of homograft skin as a temporary dressing to reduce the evaporation of water from the burned area and thus the calorie requirements.

(3) The obligatory increased energy requirements not offset by these forms of

treatment may be supplied by an enriched high calorie oral diet, supplemented in the patients with the most extensive burns by intravenous infusions of fat emulsions and solutions of carbohydrates and amino acids.

Adoption of these methods of treatment has been followed by the survival of three patients with very extensive burns and an absence of a 'stress reaction' in all the other patients treated in the warm, dry environment.

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Metabolism after surgery in the elderly

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Introduction

The geriatric population of the western world is increasing. We are faced, therefore, more and more with the need to perform major operations on elderly patients, many of whom are suffering from disorders of the cardiovascular, respiratory and renal systems. These may either limit the extent of surgery or make convalescence stormy. These patients present a challenge to all of us which can only be met by an extensive knowledge of their medical problems and their responses to operations. Surgery may affect not only the systems already mentioned, but also produce its own effects on body metabolism. It is often said that age affects the metabolic response to surgery as does the severity of trauma. We were unable to find a detailed study of these two factors in elderly patients and we felt it worth while to investigate the problem further.

Methods

Full metabolic balance studies were done in fifteen patients aged 60–79 years of age, of both sexes, who were subjected to operation. The patients were selected

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