Severe undernutrition in growing and adult animals

19*. The metabolic rates and body temperatures of calorie-deficient and protein-deficient pigs

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1. The body temperatures and resting oxygen consumptions of calorie-deficient and protein-deficient pigs have been measured at 12, 21, 26, 30, 36 and 40°.

2. A fall in the environmental temperature was followed by a rise of the same order in the oxygen consumptions of the two groups of animals, and past and present evidence indicates that the rise in normal animals of the same size is similar.

3. The rectal temperatures and oxygen consumptions of the protein-deficient pigs were higher at all the above temperatures than those of the calorie-deficient animals but not as high as those of normal animals.

4. The differences in rectal temperatures and oxygen consumptions were highly significant at 30°, which is probably within or near the zone of thermal neutrality of all the animals.

The resting metabolic rate and oxygen consumption of suckling and of undernourished, i.e. calorie-deficient, pigs were determined by McCance & Mount (1960) and in the initial stages of rehabilitation of the latter by Mount, Lister & McCance (1963). The body temperatures were below normal during severe and prolonged undernutrition and the metabolic rates per kg body-weight and m² of surface area were also well below those of normal pigs that weighed the same but were, naturally, much younger. Both the metabolic rates and the somatic temperatures rose rapidly on rehabilitation. These results were in agreement with those of Horst, Mendel & Benedict (1934) for rats and of Mount *et al.* (1963) for poultry. They are also in general agreement with the work on adult man. The findings in children have been somewhat inconsistent and were reviewed and discussed by Rutishauser & McCance (1968). A study has now been made of the resting metabolic rates in pigs whose growth rates had been limited by dietary deficiencies of protein. This work is likely to have an application to the management of children suffering from kwashiorkor, a disease prevalent in parts of the world and due to a diet containing relatively little protein, i.e. too low a protein to calorie ratio. The resting metabolic rates of such children were investigated by Montgomery (1962) and are now being reinvestigated by us.

EXPERIMENTAL

Twenty-one malnourished pigs have been used for this investigation and six normal pigs. Of the former, six were reared on the diet described by Čabak, Gresham & McCance (1962) and Lister & McCance (1967). The ration provided about 90 g

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of food (335–340 kcal) per day (McCance & Widdowson, 1966), but the exact amount was varied from time to time according to the weight and progress of the animals. Nine pigs were reared on the above rations plus as much sucrose as they would eat and two on the same basal rations plus unlimited amounts of maize oil. The feeding of these animals required considerable tact and patience for the animals were not hungry and the amount of sugar and oil they would eat varied from pig to pig and experiment to experiment. Two pigs were fed on 60 g of the basal mixture (225 kcal/day) plus either all the sugar or all the oil that they would eat. Two normal pigs were 'pair-fed' with these on the basal ration alone and remained more undernourished than the experimental ones that received 90 g of this ration/day. The animals that received the limited amount of the high-protein diet will be referred to as the undernourished group, those that received similar rations together with unlimited amounts of additional carbohydrate or fat the protein-deficient group and the fully fed but much younger animals of similar weights the normal group.

Oxygen consumption was measured by an open-system method. The animal under test was kept in a temperature-controlled respiration chamber through which room air was pumped at a constant rate. The respiration chamber (volume approximately 90 l.) was made in the laboratory workshop out of hard white plastic board. One of its sides was detachable and made of clear 'Perspex' so that the animal could be seen, and the floor was covered with a removable wooden board. The whole chamber was housed inside an insulating framework within which were fitted four water radiators. Expanded polystyrene was used as insulating material. A thermostatically controlled refrigerator and immersion heater were used to regulate the temperature of water held in a tank, for circulating through the radiators. This equipment was housed separately to reduce the amount of noise and vibration reaching the animal. A small electric fan was fitted inside the insulating framework to maintain an even distribution of temperature inside it, and the corrugated plastic tubing which led from the air inlet to the chamber was closely applied to one of the radiators so that air entering the chamber would be warmed or cooled according to the working temperature.

The oxygen content of the air entering and leaving the chamber was determined by a thermal conductivity method with a Universal Diaferometer MG4 (Kipp & Zonen, Delft, Holland).

Following the introduction of the animal to the chamber an interval of 1–2 h was allowed for its metabolic rate to adjust to the thermal conditions required for the test. The oxygen consumption was then recorded continuously for approximately 30 min. Only recordings which showed a reasonably steady rate of oxygen consumption were accepted.

To familiarize the animals with this procedure a period of training was given before any measurements were made. This involved putting the animal into a darkened box simulating the respiration chamber for several sessions of 2 or 3 h at a time. Following this it was found that most of the animals settled down quickly and remained quiet on the occasion of the actual test. Measurements were made in most instances 2·5–6 h after a feed.

The chamber temperature recorded was the mean value obtained from two or three thermometers placed at different positions within the chamber. Frequent readings during the period of test showed only small variations of the order of 0·5°.

Rectal temperature was measured just before the animal was placed in the respiration chamber and immediately after it was taken out at the end of the test. An ordinary glass clinical thermometer was used which was inserted to a depth of 6 cm and maintained carefully in this position for 2–3 min before the reading was taken.

Skin temperature was also taken over the anterior abdominal wall at the start and finish of each test. The mean value of several readings taken at different positions was recorded. An electronic Dependatherm thermometer (Kane-May Ltd, Welwyn Garden City, Herts.) was used.

Oxygen consumption was determined at various ages, but the majority of measurements were made at about 13 months.

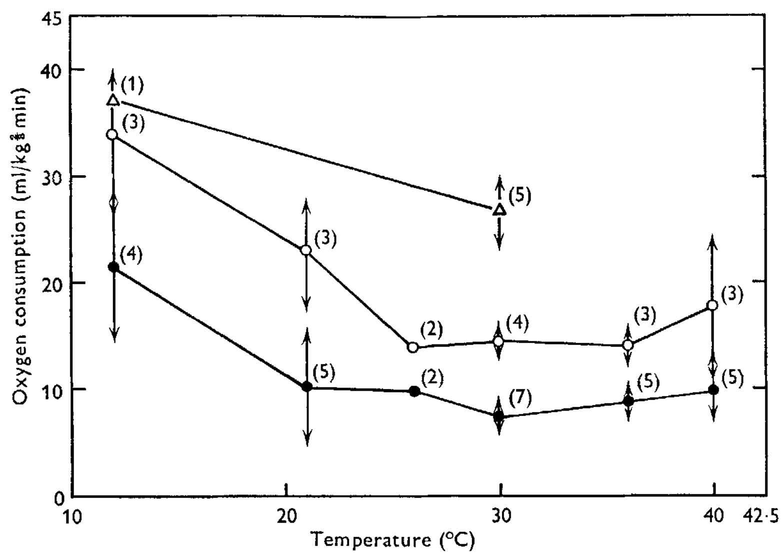

Fig. 1. The effect of environmental temperature on the oxygen consumption of normal (△), protein-deficient (○) and undernourished (●) pigs. The numbers of determinations at each temperature is shown in parentheses and arrows indicate the standard deviations.

RESULTS

Fig. 1 shows the mean oxygen consumption/kg$^{\frac{3}{4}}$ per min of four undernourished and three protein-deficient animals at six different chamber temperatures, and also the oxygen consumption of one normal animal at 12° and the mean oxygen consumption of five normal animals at 30°. The results for the undernourished pair-fed animals are included in these values. It was originally planned to use only such animals for these extensive temperature comparisons, but when it was found that weight appeared to make little difference to oxygen consumptions when expressed per unit weight$^{\frac{3}{4}}$ the results for other animals were included. The mean weights were: of undernourished animals 6·5 kg ± 1·0; of protein-deficient animals 9·3 kg ± 4·8 and of normal animals 7·1 kg ± 2·8. The protein-deficient animals had oxygen consumptions at each temperature between those of normal and the undernourished animals, but with the limited numbers available these differences were not always significant. The values, however, do indicate that 30° is probably within or not far below the zone of thermal neutrality for both the undernourished and protein-deficient animals.

Seven protein-deficient animals were studied at 12° and with the additional numbers the mean oxygen consumptions were 21.4 ± 6.9 and 37.4 ± 5.7 for the undernourished and protein-deficient animals respectively and the difference was significant ($P < 0.01$). The mean rectal temperatures of the undernourished and protein-deficient animals were less than 35° and 37.6° respectively after the tests were over and this difference was more significant ($P < 0.001$).

Most of the observations were made at 30°, and Table 1 shows the mean ages, weights, oxygen consumptions, rectal and skin temperatures. The difference between the oxygen consumption of the undernourished and the protein-deficient animals was highly significant ($P < 0.001$) as was that between the protein-deficient and the normal ones. The differences between their rectal temperatures were equally significant but those between their skin temperatures less so or not significant.

Table 1. *Mean values and standard deviations for ages, weights, oxygen consumptions, rectal and skin temperatures of calorie-deficient, protein-deficient and normal pigs at* 30°

Nature and no. of animals	Weight (kg)	Age (months)	Oxygen consumption (ml/kg$^{\frac{3}{4}}$ min)	Rectal temperature (at end of test) (°C)	Skin temperature (at end of test) (°C)
Normal controls, 5	6.7 ± 2.9 (5)	0.7 ± 0.3 (5)	26.7 ± 3.3 (5)	40.0 ± 0.4 (3)	36.1 ± 0.6 (3)
Calorie-deficient, 8	6.3 ± 1.0 (15)	12.2 ± 2.6 (15)	9.1 ± 2.0 (15)	36.9 ± 0.6 (10)	34.1 ± 0.9 (11)
Protein-deficient, 13	11.1 ± 3.8 (18)	12.4 ± 1.5 (18)	15.4 ± 2.4 (18)	38.6 ± 0.5 (16)	35.5 ± 0.7 (15)

Figures in parentheses are the numbers of observations.

DISCUSSION

These results are in line with the observations reported by McCance & Mount (1960) and by Mount *et al.* (1963) on the body temperature and oxygen consumption of normal and of undernourished, i.e. calorie-deficient, pigs. They extend the results of McCance & Widdowson (1966) who showed that pigs with protein deficiency were not so vulnerable to cold as the more wasted calorie-deficient ones, and of Brenton, Brown & Wharton (1967) and of Wharton (1968) who showed a greater susceptibility to cold in the more wasted of a group of children suffering from kwashiorkor. The results on the oxygen consumption of calorie-deficient pigs are those which one would have expected from previous work on animals and adult man but the literature on the oxygen consumption of malnourished infants is full of contradictions (Rutishauser & McCance, 1968). Part of the uncertainty has been due to the failure of some workers to separate their cases of marasmus accurately enough from those of kwashiorkor. It was suggested by the last pair of authors that part of the difficulty had been due to the way in which the word 'undernourished' had been interpreted. Some had confined it to untreated children, others to children who were still undernourished but had been undergoing treatment for some time and were already well on the way towards rehabilitation. This explanation is borne out by the work of Mönckeberg, Beas, Horwitz, Dabancens & Gonzales (1964) and Mönckeberg (1968), although their results are not easy to compare with those of others because they were expressed in rather an unusual way, i.e. per unit of length rather than per unit of weight or of surface area. These doubts must remain until calorie deficiency and protein deficiency have been clinically and biochemically diagnosed in infants in which oxygen consumption can be measured before and after rehabilitation. Until the active metabolic mass of the body can be measured more accurately during life, there seems to be a strong case for expressing the results per unit of surface area or per $W^{\frac{3}{4}}$.

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