Archives of Disease in Childhood, 1983, **58**, 504–508

Incubation of very immature infants

A E WHELDON AND D HULL

Department of Child Health, University Hospital, Nottingham

SUMMARY The range of thermal control and the thermoneutral range of preterm infants under 30 weeks' gestation was calculated by extrapolation of data from studies on more mature infants. Even assuming some thermoregulatory capacity, the range of control is less than 3°C, the thermoneutral range is less than 0·5°C, and both are greatly influenced by the rate of transepidermal water loss. Measurements of metabolic rate and effective thermal environment made on 6 infants under 30 weeks' gestation in the first week of life showed that the very preterm infant exerts little thermoregulatory control and that variations in transepidermal water loss are a major factor determining the appropriate thermal environment.

The survival rate of infants under 30 weeks' gestation has improved dramatically in recent years from below 10% to between 40 and 60%.[1 2] Undoubtedly, the skillful application of new techniques in respiratory and nutritional support has made a considerable contribution, but nevertheless many very preterm infants now survive without either. This suggests that other factors, such as an increased awareness of and responsiveness to the nature and special environmental requirements of very preterm infants contribute to the improvement.

Current policy is to nurse very preterm babies in incubators or under radiant warmers, methods which have been used successfully for small babies born later in gestation. The aim is to provide an appropriate ambient temperature and humidity while protecting the infant from infection and other environmental hazards, but providing warmth is the most important requirement.

The relation between an infant—even a newborn infant of 30 weeks' gestation—and his or her thermal environment is governed by the same factors that operate in adults. The heat generated by the life processes is lost to the environment through radiation, convection, evaporation, and conduction. The 2 nursing systems (incubators and radiant warmers) use different strategies to keep the overall heat loss within acceptable limits. A baby incubator provides a small warm room, where both radiant and convective heat losses are reduced, while a radiant heater over the baby's bed leads to a net radiant heat gain and a high rate of heat loss by convection to the cool room air.[3]

For babies over 32 weeks' gestation there is sufficient information available to permit the construction of metabolic diagrams that illustrate the ambient temperature range that these infants may be expected to tolerate (range of thermal control) or that would subject the infant to minimal thermal stress (thermoneutral range). Those calculated by Hey[4] have been used extensively as a guide to clinical practice. For the relatively more mature infants the incubator and radiant heater seem adequate because they control the thermal environment within a temperature range that the infants can tolerate.

There is little information, however, on the best thermal environment for infants under 30 weeks' gestation in the early weeks of life. We have constructed a metabolic diagram on the basis of extrapolation of measurements made on more mature infants. These calculations suggest that the range of thermal control is very narrow. We also report measurements made on infants in the first week of life who were 30 weeks' gestation or under and relate these measurements to the theoretical metabolic diagram.

Theoretical considerations

Construction of a metabolic diagram starts from the steady state equation for heat balance that states that the heat produced by metabolism (M) is dissipated to the environment through non-evaporative (H) and evaporative (E) means, thus:

(1) $M = H + E$

Non-evaporative heat loss is effectively proportional to the temperature difference between the body surface (T_s) and the environment (T_e), where the latter accounts for the temperatures of both the surrounding air and the surrounding radiant surfaces, thus:

$$(2)\ H = (T_s - T_e)/I_e$$

where I_e is the thermal insulation of the environment. Similarly, internal heat transfer to the skin is proportional to the difference between core (T_c) and skin temperatures, thus:

$$(3)\ M = (T_c - T_s)/I_t$$

Elimination of skin temperature between equations (1), (2), and (3) allows the heat balance equation to be written as;

$$(4)\ T_c = T_e + M\,(I_e + I_t) - EI_e$$

and shows the relation between body core temperature and environmental temperature. This equation also identifies the physiological mechanisms by which core temperature can be maintained if environmental temperature changes—that is, variations in evaporative heat loss (sweating), variations in tissue insulation (vasoconstriction and vasodilation), and variations in metabolic heat production.

The metabolic diagram developed by Mount[5 6] shows the variations in heat production and heat loss used to maintain Tc when Te varies. It assumes that the physiological responses from hot to cold—sweating, vasomotor adjustments, and thermoregulatory heat production—occur in sequence and that the infant's posture does not change. Fig. 1 shows the metabolic diagrams for an adult and for a newborn term infant weighing 3 kg, using data taken from published reports[7–10] and assuming that the core temperature stays at 37°C. The metabolic diagram shows both the overall range of thermal control (over which core temperature is maintained) and the thermoneutral range. The latter is important because in it lies the zone that both man and animals select for thermal comfort. It is clear that the thermoneutral range is narrower and at a higher environmental temperature for a baby than for an adult.

Very preterm infants differ in 2 important respects from term infants. Firstly, they are unable to sweat,[11] and secondly, they may have very high transepidermal water losses owing to the permeability of their immature skin.[12] For the calculation it was assumed that they could make appropriate vasomotor responses and thus influence tissue insulation and that they responded to cold exposure with an increase in heat production. We know of no evidence that infants under the age of 10 days, born before 30 weeks' gestation, are able to achieve either; but likewise, we have no evidence that they cannot. Fig. 1 also shows the metabolic diagram of a 1 kg baby with an assumed metabolic rate of 18 W/m², which is equivalent to a rate of oxygen consumption of 5 O_2 ml/kg/min, and a transepidermal water loss causing a heat loss of either 5 W/m² or 25 W/m²—the first being that of an infant with well formed keratin, the second that often found in preterm infants in the first days of life.[12]

These figures show that the thermoneutral range would be very narrow, less than 0·5°C; and the range of thermal control, even if the infant could sustain a 2 fold increase in heat production, would still be less than 3°C. The level of the thermoneutral range depends heavily on the rate of transepidermal water loss.

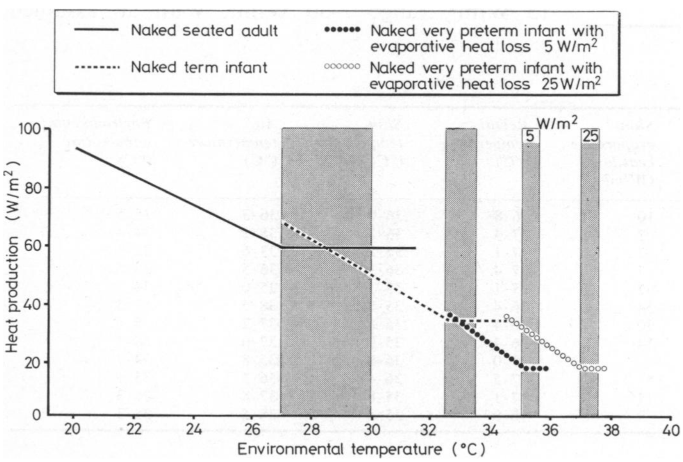

Fig. 1 *Metabolic diagrams showing metabolic heat production at different environmental temperatures: seated adult, a naked term infant, and a naked very preterm infant with evaporative heat losses of 5 W/m² and 25 W/m². The shaded areas show the thermoneutral range and the extent of the lines shows the range of thermal control.*

Subjects and methods

We studied 6 infants born at 30 weeks' gestation or less. Assessment of gestational age was based, where possible, on the mother's menstrual history and confirmed by clinical assessment. All the infants were breathing spontaneously and were being nursed naked (except for disposable napkins) in incubators at the time of study. The details of the infants are given in Table 1.

Metabolic heat production was calculated from the rate of oxygen consumption, assuming that 1 ml O_2 (STP) produces 20·3 joules of heat. Body surface area was calculated from the Boyd formula.[13] The rate of oxygen consumption was measured for at least 5 minutes, using an open circuit system in which the baby's expired gas was entrained in a flow of ambient air drawn through a clear plastic funnel held lightly over the nose and mouth. The rate of oxygen uptake was calculated from the product of the concentration difference in ambient air and mixed expired gas and the flow rate through the system. Oxygen concentration was measured in dried gas using a paramagnetic analyser (OA 260, Servomex). Skin evaporative water loss was measured in 6 sites using an Evaporimeter (Ep 1, Servomed).[14] Each reading was corrected for shielding values, weighted according to the surface area that it represented, and multiplied by the latent heat of vaporisation of water to give an evaporative heat loss. Rates based on these calculations are similar to those obtained by other methods.[15] The infant in case 5 was nursed in high humidity and measurements of evaporative water loss were not made.

Core temperature was measured as deep rectal temperature, using a polyethylene sleeved thermocouple inserted to a depth of about 5 cm. Skin temperature was measured at the same 6 sites as water loss using a radiant thermometer (KT 41, Heimann) and the weighted mean value calculated. Air temperature was measured using a thermocouple suspended 9 cm above the baby. The environmental temperature was estimated by subtracting the difference between incubator and room air temperatures multiplied by 0·14, from incubator air air temperature.[16] All measurements were made when the infants were lying quietly and were being fed continuously either intravenously or intragastrically.

Each baby was studied initially in the environmental conditions selected by the nursing staff. In the infant in case 2 measurements were repeated at a different ambient temperature and in the infant in case 6 at a different humidity. The environment was left to stabilise for at least 45 minutes before measurements were made.

Table 1 *Gestation, body weight, and age of infants in study*

Case No	*Gestation (weeks)*	*Birth weight (kg)*	*Age at study (days)*
1	30	1·12	1
2	30	1·03	1, 7
3	29	1·08	1, 3
4	28	0·74	2
5	28	0·63	2, 5
6	30	1·12	4

Results

Table 2 gives the results of the measurements made in the first week of life on 6 preterm infants. The mean metabolic rate of infants on days 0 to 2 was 18 W/m^2, range 15–20 W/m^2; and on days 3 to 7 was 20 W/m^2, range 18–22 W/m^2. The mean evaporative heat loss from the skin of infants on days 0 to 2 was 18 W/m^2, range 7–54 W/m^2; and on days 3 to 7 was 13 W/m^2, range 7–30 W/m^2. With an assumed

Table 2 *Measurements on infants in study*

Case No	*Postnatal age (days)*	*Oxygen consumption (ml/kg/min)*	*Metabolic rate (W/m²)*	*Skin evaporative heat loss (W/m²)*	*Rectal temperature (°C)*	*Skin temperature (°C)*	*Air temperature (°C)*	*Environmental temperature (°C)*
1	1	4·5	17	10	36·8	36·0	36·3	35·5
2	1	5·5	20	7	37·4	36·2	35·2	34·4
	1	5·6	20	7	37·1	35·2	33·6	32·9
	7	6·0	22	7	37·4	36·3	36·5	35·5
	7	5·7	21	7	37·1	35·3	35·0	34·2
3	1	5·1	19	54	36·4	35·9	38·5	37·5
	3	5·3	18	30	36·4	35·8	37·7	36·6
4	2	6·0	19	14	36·4	35·9	37·0	36·1
5	2	4·8	15	*	37·0	36·0	35·8	34·7
	5	6·4	19	*	37·5	36·4	36·5	35·1
	5	6·2	19	11	37·1	35·8	37·8	36·3
6	4	5·9	21	9	36·9	35·5	36·5	35·3

*This baby was nursed in a high relative humidity.

respiratory evaporative heat loss of 3 W/m^2 [3] this gives a mean evaporative heat loss of 19 W/m^2, range 10–57 W/m^2. In the theoretical calculation 25 W/m^2 was the figure used for the higher evaporative heat loss. Thus some infants required ambient temperatures even higher than those shown in Fig. 1. The extreme sensitivity of this group of infants is shown by the finding that only the infant in case 2, who had a relatively low transepidermal water loss, was nursed in an incubator air temperature that was more than 0·5°C below core temperature. For many infants the incubator air temperature was higher than core temperature. Despite an air temperature of 38·5°C, the infant in case 3 had a rectal temperature of only 36·4°C. The infant in case 5 was routinely nursed in a high humidity to reduce the rate of water loss from her skin and the incubator was servo-controlled to skin temperature. Within an hour of emptying the reservoir of the humidifier, her rectal temperature had fallen by 0·4°C even though the incubator air temperature had risen by nearly 1·5°C.

Discussion

The study measurements and the theoretical relation between environmental temperature and metabolic rate are shown in Fig. 2. The theoretical relation was

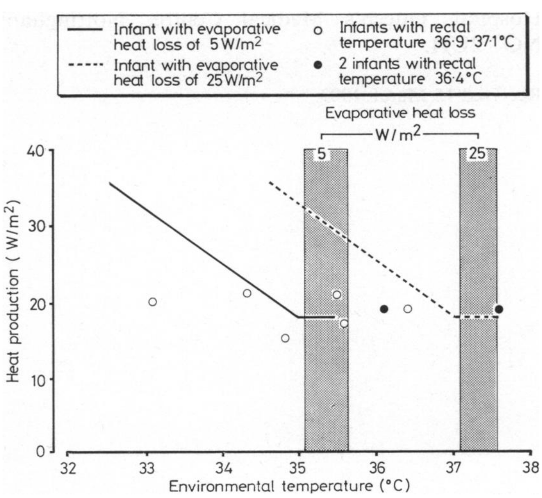

Fig. 2 *Theoretical rates of heat production required to maintain a rectal temperature of 37°C at different environmental temperatures for an infant with evaporative heat losses of 5 W/m² and 25 W/m². The study measurements are represented by circles. The shaded areas are the thermoneutral ranges, assuming vasomotor and postural adjustments.*

calculated on the assumption that the core temperature was held at 37°C, while in the study the infants' rectal temperature varied from 36·4 to 37·5°C. The extent to which this rectal temperature reflected deep core temperature is not known. In some infants it was only 0·5°C higher than the mean surface temperature. In general, the theoretical and study values were similar for infants in the resting state. The variation in the required environmental temperatures was largely determined by the rate of transepidermal water loss. Some infants seemed to tolerate lower environmental temperatures than those predicted but there was, however, no evidence that the infants made appreciable thermoregulatory responses. Those with low rectal temperatures or in cooler environments did not have higher metabolic rates than those with higher temperatures or in warmer surroundings and we still do not know whether they have any capacity for thermoregulatory thermogenesis. For clinical purposes it seems wise to assume that they do not.

From the theoretical diagram it seems that vasomotor and postural adjustments would exert only a small effect, even if they were present. Clinical observations of these bright red, glazed, and relatively inactive infants suggest that there is no thermoneutral range, and this is supported by a failure to define the range of thermal control because thermoregulatory mechanisms of generating extra heat or increasing heat loss (sweating) are weak or not present.

The ambient temperature appropriate to hold the infant's body temperature around 37°C is determined by his size, metabolic rate, and rate of transepidermal water loss. Between babies, size and metabolic rate vary little compared with differences in transepidermal water loss that depend on the maturation of the skin, and in particular on the deposition of keratin. Preterm birth seems to accelerate skin development with a subsequent reduction in water loss. If transepidermal water loss is reduced, by applying creams or nursing the infants in high humidity, the range of environmental temperature in which to nurse infants would be narrow and around 35°C. The translation of this temperature into the temperature setting for an incubator or radiant heater depends on the characteristics of the system. In infants in incubators with a rapid air change the associated mean skin and air temperatures are shown in Table 2. Only in the infant in case 5, however, was transepidermal loss reduced by high humidity. Both the application of barrier creams and maintenance of high humidity are technically difficult to achieve and interfere with other aspects of the infant's care, but it must be assumed that in all innovations in neonatal care risks will come with the benefits. Both the application of cream and nursing infants in high humidity were practised 20–25 years ago; both were discontinued because they increased the risk of infection. Their reintroduction demands close surveillance, not only in respect of infection but also of the consequences on the infant's fluid balance.

It seems that very preterm infants need to be 'incubated' in much the same way as eggs. If this view is correct we need to reconsider the environment we provide for these infants, the sensitivity of our control, and the channels and criteria by which their attendants have access to them.

As the infant emerges from this state and develops his own systems of thermoregulatory control, the environment needs to be relaxed appropriately. One major factor is the rate of transepidermal water loss. It is arguable that this should be measured with the same diligence as we record arterial oxygen concentration and fluid intake. Likewise there might be virtue in assessing more formally the infant's ability to tolerate and respond to fluctuations in environmental temperature.

References

1 Stewart AL, Reynolds EOR, Lipscomb AP. Outcome for infants of very low birth weight: survey of world literature. *Lancet* 1981; **i**: 1038–41.

2 Orgill AA, Astbury J, Bajuk B, Yu VYH. Early development of infants 1000 g or less at birth. *Arch Dis Child* 1982; **57**: 823–7.

3 Wheldon AE, Rutter N. The heat balance of small babies nursed in incubators and under radiant warmers. *Early Hum Dev* 1982; **6**: 131–43.

4 Hey EN. The relation between environmental temperature and oxygen consumption in the new-born baby. *J Physiol (Lond)* 1969; **200**: 589–603.

5 Mount LE. The concept of thermal neutrality. In: Monteith JL, Mount LE, eds. *Heat loss from animals and man*. London: Butterworth; 1974: 425–39.

6 Mount LE. *Adaptation to the thermal environment: man and his productive animals*. London: Arnold, 1979.

7 McIntyre DA. *Indoor climate*. London: Applied Science Publishers, 1980.

8 Hill JR, Rahimtulla KA. Heat balance and the metabolic rate of new-born babies in relation to environmental temperature; and the effect of age and of weight on basal metabolic rate. *J Physiol (Lond)* 1965; **180**: 239–65.

9 Sulyok E, Jéquier E, Prod'hom LS. Respiratory contribution to the thermal balance of the newborn infant under various ambient conditions, *Pediatrics* 1973; **51**: 641–50.

10 Wheldon AE. Energy balance in the newborn baby: use of a manikin to estimate radiant and convective heat loss. *Phys Med Biol* 1982; **27**: 285–96.

11 Harpin VA, Rutter N. Sweating in preterm babies. *J Pediatr* 1982; **100**: 614–8.

12 Rutter N, Hull D. Response of term babies to a warm environment. *Arch Dis Child* 1979; **54**: 178–83.

13 Boyd E. *The growth of the surface area of the human body*. Minneapolis: University of Minnesota Press, 1935.

14 Nilsson GE. Measurement of water exchange through skin. *Med Biol Eng Comput* 1977; **15**: 209–18.

15 Wheldon AE. Heat exchange between the newborn baby and the environment. PhD thesis, Nottingham University 1982.

16 Hey EN, Mount LE. Heat losses from babies in incubators. *Arch Dis Child* 1967; **42**: 75–84.

Correspondence to Professor D Hull, Department of Child Health, Floor E, East Block, University Hospital, Queen's Medical Centre, Nottingham NG7 2UH.

Received 15 March 1983