Effect of Humidity on Production and Loss of Heat in the Newborn Baby

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In 1955 Clement Smith wrote: 'Most of us who work in neonatal pediatrics are distressingly familiar with the sight of a small infant surrounded by a fog of vapour within a closed tent or incubator. This situation perhaps symbolizes the present status of this subject, which is essentially a very small body of facts enveloped in a misty atmosphere of speculation, which is walled off from its surroundings by a rigid container of prejudice.' The facts available are still, unfortunately, almost as scanty today as they were in 1955. Since the classic paper of Blackfan and Yaglou appeared in 1933, it has been generally accepted that a moderately high relative humidity is a useful adjunct to the regulation of a baby's body temperature; Day, Curtis, and Kelly, in 1943, showed that up to a quarter of a baby's basal heat loss might be due to evaporation of water from the skin and respiratory tract. We have, therefore, tried to estimate the effect of the relative humidity of the air on total heat production and loss in normal, naked, newborn babies under controlled environmental conditions.

Material and Methods

A total of 48 healthy full-term newborn babies has been studied, unsedated between feeds, with the consent and co-operation of their parents, in a specially constructed Perspex metabolic chamber (Fig. 1), in which the infants' oxygen consumption can be measured continuously and the thermal environment controlled and altered at will (Hill, 1959; Hill and Rahimtulla, 1965). The infants were between 1 and 17 days old and weighed between 2·5 and 3·9 kg. (average age 5 days; average weight 3·23 kg.). Each infant was studied at two environmental temperatures, one (about 35° C.) in the thermo-neutral range and the other (about 31° C.) below this range, when the infant had to increase its heat production and oxygen consumption to maintain a normal body temperature. The infants were naked except for a urine bag (Baldwin *et al.*, 1962) and a small stockinette napkin. They were placed supine on a

concave polyethylene tray of low thermal conductivity within a horizontal cylindrical chamber 48 cm. long and 16 cm. in diameter. At both environmental temperatures oxygen consumption and heat balance were assessed at two relative humidities.

The measurements were made over a 10-minute period about 20 minutes after the change of environment. Care was taken to ensure that temperature and vapour pressure had stabilized before measurements were made, and the order in which the observations were made was varied randomly. There was no visual evidence that any of the babies sweated during these studies, nor were any measurements taken if the napkin was wet or soiled. Any marked increase in water loss would have been detected as an increase in the difference between the absolute humidity of air entering and leaving the chamber. The infant was watched carefully and activity assessed on an arbitrary 5-point scale every 2 minutes (Hill and Rahimtulla, 1965). In the first main series of tests the effects of low (20%) and moderate (45%) humidity on heat production and heat loss were compared. The differences detected were small. A further series of 19 infants was therefore studied at an environmental temperature of 31° C. when relative humidity was varied between 22 and 85%. It was, unfortunately, not possible to make similar tests at 35° C., as it was not possible to achieve a reliable and stable humidity in excess of 60% at this temperature.

The quoted environmental temperature is the operative environmental temperature (T_o) (Winslow, Herrington, and Gagge, 1937), calculated from a knowledge of water-jacket temperature and the known relation between this and mean air (T_a) and surface temperature (T_s) within the chamber when an infant is present. Mean air temperature never differed from mean surface temperature by more than 0·8° C., nor operative temperature from water-jacket temperature by more than 1·0° C. Air movement within the chamber was measured directly with a hot wire anemometer and found to be between 4 and 5 cm./sec. with a baby present. Radiant heat loss is thought to be as important as convective loss at this low and constant air speed, so operative temperature was calculated from the simplified relation $T_o = 0·5T_a + 0·5T_s$.

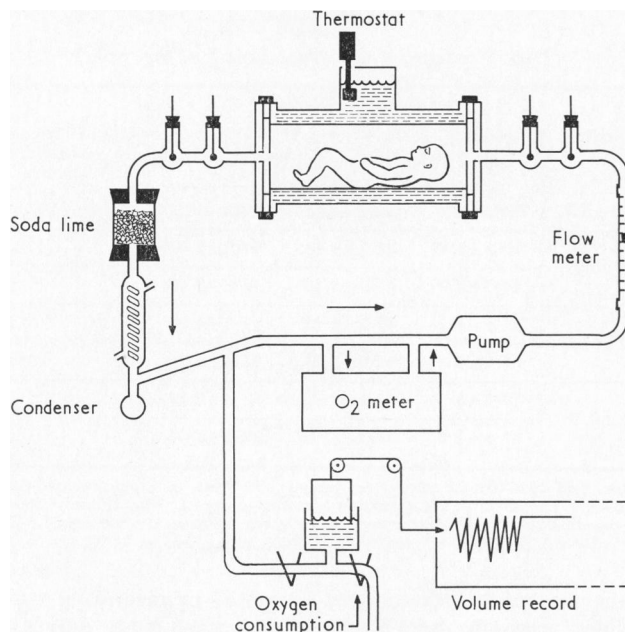Heat production was calculated from measured oxygen consumption on the assumption that 1 ml. O_2 at STPD

Fig. 1.—*Outline diagram showing the main components of the metabolic chamber.*

= 4·8 cal. The errors inherent in this assumption have been well discussed by Karlberg (1952). The actual value will vary between extremes of 4·7 and 5·0 depending on the proportions of protein, fat, and carbohydrate being metabolized. Rectal temperature was monitored continuously with a thermocouple at a depth of 5–10 cm. Heat storage was calculated from the change in rectal temperature assuming that 0·83 calories are necessary to warm 1 g. body tissue 1° C. (Burton and Edholm, 1955). In the later experiments 4 representative skin temperatures were also measured continuously with 36 s.w.g. thermocouples held in place with plaster tape, and an average skin temperature calculated from the weighting factors of Klein and Scammon (1930). In these cases the change in body temperature (ΔT) and the resulting change in heat content were calculated from the change in rectal temperature (ΔR) and skin temperature (ΔS) using the relation $\Delta T = 0 \cdot 7 \Delta R + 0 \cdot 3 \Delta S$ (Burton and Edholm, 1955). The changes in heat content calculated on this basis differed little from those calculated from the changes in rectal temperature only. The values for heat loss in this paper were then obtained from the measured calorie production plus or minus the assessed change in the heat content of the body.

Absolute humidity in the chamber was controlled and varied by altering the temperature of a cold water condensing tower in the recirculating system. Relative humidity could be predicted from a knowledge of this condenser dew-point and of air temperature within the chamber. Absolute humidity levels were checked with a dew-point meter and with wet- and dry-bulb thermo-meters located near the inlet and outlet from the chamber. (Air speed past the thermometers was greater than 3 metres/sec.) The quoted relative humidity was calcu-lated from the mean of the pre- and post-chamber absolute humidity readings at average chamber air temperature. Evaporative heat loss and water loss were related on the assumption that the evaporation of one gram of water from the skin results in the loss of 600 calories of heat from the body (Hardy, 1949).

Results

At an operative environmental temperature of about 35° C. (mean ± SD: 35·1 ± 0·2° C.) the oxygen consumption values are comparable with the basal values established by Hill and Rahimtulla (1965) for full-term infants of similar age in a neutral thermal environment, using the same metabolic chamber. Rectal temperature also rose slowly in every case where it was initially below 37·2° C. This supported the assumption that such a temperature was never below the neutral range appropriate for the infants studied. In contrast, at an operative temperature of about 31° C. (31·1 ± 0·3° C.), at all three levels of relative humidity studied, every infant increased its heat production at least 15%. Nevertheless, in most cases rectal temperature fell slightly. It is clear, therefore, that this environmental temperature was below the neutral range.

TABLE

Heat Production and Heat Loss (cal./kg. min.)

No. of Experiments	Environmental Temp. (°C.) Mean ± SD	Rectal Temp. (°C.) Mean ± SD	Relative Humidity (%) Mean ± SD	Heat Produced Mean ± SD	Heat Lost Mean ± SD	Mean Difference in Heat Production Mean ± SEM	Mean Difference in Heat Loss Mean ± SEM	Predicted Difference in Respiratory Heat Loss
11	31·1 ± 0·30	36·8 ± 0·32	19·2 ± 1·8	42·7 ± 5·04	48·8 ± 5·73	−1·66 ± 1·51	−2·00 ± 0·69 p < 0·05	−1·1
			44·5 ± 2·4	41·0 ± 4·15	46·8 ± 5·92			
13	31·2 ± 0·26	36·7 ± 0·40	22·5 ± 4·1	45·0 ± 6·24	47·5 ± 4·84	−2·09 ± 1·34	−5·10 ± 0·94 p < 0·001	−2·7
			85·0 ± 2·8	42·9 ± 3·48	42·4 ± 3·50			
13	35·1 ± 0·20	36·8 ± 0·36	18·6 ± 5·3	34·6 ± 2·90	28·6 ± 5·72	+0·14 ± 0·75	−1·49 ± 1·36 p > 0·3	−1·4
			47·8 ± 1·5	34·7 ± 4·92	27·8 ± 6·76			

Note: Mean heat production and heat loss in calories/kg. min. at the levels of humidity investigated together with mean paired differences and tests of significance. The effect of the change in humidity on predicted evaporative heat loss from the respiratory tract is also given in the same units, based on an assumption that expired air leaves the nose 90% saturated 1° C. below deep body temperature, and that pulmonary ventilation is 160 ml. BTPS/kg. min. at 35° C. and 200 ml./kg. min. at 31° C.

The Table summarizes the results obtained in those infants who remained relatively quiet while comparative measurements were made at two different relative humidities. Certain infants became periodically restless and there was some doubt if valid comparisons could be made with confidence. It was, therefore, arbitrarily decided to exclude from analysis all the studies in which the child had shown more than minimal activity (activity score ≥ 2). The infants were more consistently active at the lower temperatures, but there was no evidence that changes in relative humidity influenced the degree of activity. Paired-variate t-tests at 31° C. revealed that changes in humidity of 25 and 63% produced significant changes in heat loss. The changes in heat production were smaller and more variable; the mean change for all 24 tests was, however, just significant at the 7% level (1·89 ± 0·98 cal./kg. min.; $p = 0·07$). At 35° C., in contrast, heat loss was only slightly and rather variably affected by a 29% change of humidity, and heat production remained unaltered. Environmental temperatures were similar at the time the paired comparative measurements were made, and paired variate tests revealed no significant difference in body temperature or activity.

Discussion

Changes in the humidity of the air would be expected to influence heat balance chiefly because of their effect on evaporative loss, but there might well be secondary effects on, for example, skin temperature. Evaporative heat loss is usually assessed by measuring water or weight loss, but in the present study only total heat production and loss were measured. This gives, however, a direct measure of the *over-all* effect of a change of humidity on an infant's heat balance.

At 35° C. no consistent changes in heat production occurred with moderate changes in humidity (Fig. 2). Average heat loss was slightly greater at low humidity (Fig. 3), but the effect was only marked in the 6 infants who had a rectal temperature below 36·8° C. at the time the measurements were made. Vasodilatation normally occurs at this temperature when rectal temperature is normal or raised (Brück, 1961; Young, 1962), and once this heat-regulating mechanism has come into play it is less likely that any difference in total heat loss would remain detectable.

At 31° C. average heat production (Fig. 2) and heat loss (Fig. 3) both changed when humidity changed. The effect on heat loss was greater and more consistent than the effect on heat production. At this temperature the skin is fully vasoconstricted and thermal conductivity is at a minimum (Day et al., 1943; Brück, 1961), and there is no evidence that changes in humidity cause changes in the infant's thermal conductivity at temperatures below the thermoneutral range. It seems likely, therefore, that the small but significant changes in total heat loss were due to changes in evaporative heat loss.

Levine, Kelly, and Wilson (1930) established that basal insensible weight loss in the clothed newborn baby is approximately 1 g./kg. hour, and that between 85 and 90% of this weight loss is due to water loss through the skin and respiratory tract.
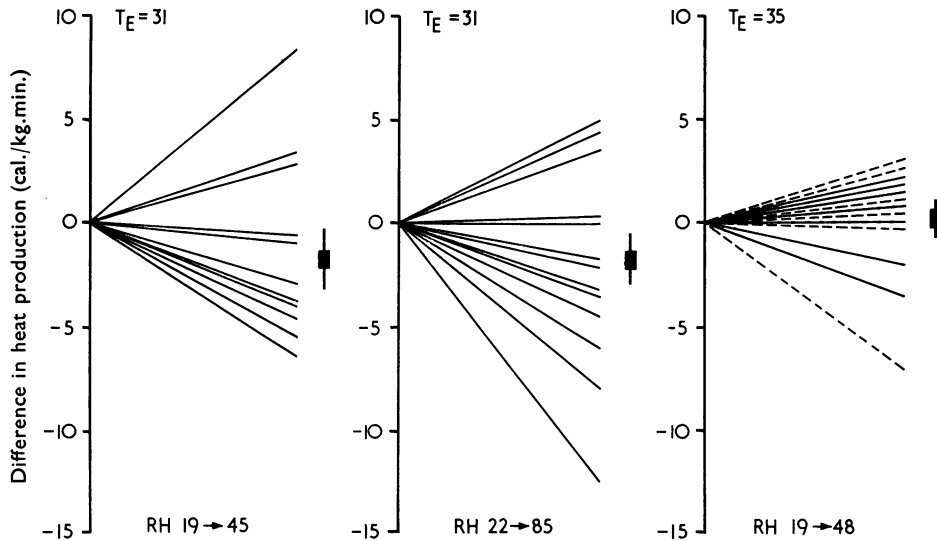
FIG. 2.—*The effect of changes of humidity (RH) on heat production in cal./kg. min. Paired comparisons at 31° and 35° C., with the mean difference $\pm SE$ of the mean indicated on the right by the square symbol and bar. Six infants had rectal temperatures below 36·8° C. at the time measurements were made in an environmental temperature of 35° C.; these results are indicated by dotted lines.*

Direct estimates of water loss for the naked baby over a range of environmental temperatures (Day *et al.*, 1943) were similar and would account for a basal evaporative heat loss of about 9 cal./kg. min. This figure is about a quarter of the infant's basal heat production under thermoneutral conditions, a fraction similar to that consistently found in adults (Benedict and Root, 1926).

Part of the evaporative loss occurs via the respiratory tract. In adults expired air leaves the nose 90% humidified at a temperature within two degrees of deep body temperature (Burch, 1945a, b; McCutchan and Taylor, 1951; Walker, Wells, and Merrill, 1961). The same probably holds true for the newborn baby, though the available evidence is not very satisfactory (Hooper, Evans, and Stapleton,
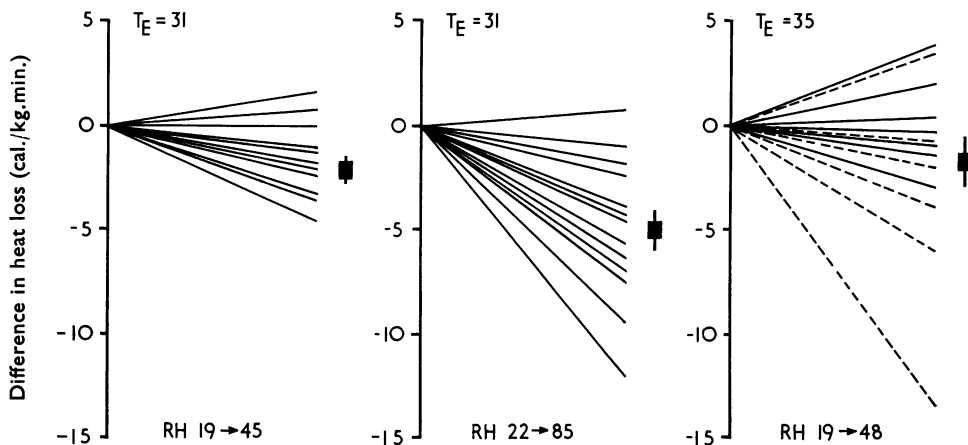

FIG. 3.—*The effect of changes of humidity on heat loss in cal./kg. min. Paired comparisons at 31 and 35° C. Symbols as in Fig. 2.*

1954; Bruck, 1962; Bruck and Paa, 1965). The total evaporative loss from the respiratory tract will thus depend on the difference in the absolute humidity of the inspired and expired air and the amount of air breathed. Breathing air of moderate humidity at room temperature (50% RH at 22° C.), the loss amounts to about 3 cal./kg. min. or a third of the total evaporative loss, a fraction again similar to that found in adults. If we make certain assumptions (Table) about pulmonary ventilation, it is possible to calculate the probable effect of changes in humidity on evaporative heat loss from the respiratory tract. These calculations suggest that more than half the measured change in heat loss at 31° C. reported here can be accounted for by changes in evaporative loss from the respiratory tract, and that a change of relative humidity from 22 to 85% reduces evaporative heat loss from the skin to only a limited extent.

On theoretical grounds a change in evaporative and total heat loss would be expected to alter the environmental temperature's neutral range. An increase in relative humidity should cause a fall in the minimum temperature lying within the predicted thermoneutral range or the predicted lower critical temperature as it has been termed. A clear exposition of this method of analysis has been given by Hill (1961a, b). Estimates of this critical temperature for full-term newborn babies have varied quite widely. Hill and Rahimtulla (1965) suggested that the reason for the difference between their findings and those of Brück (1961) lay in the differing humidity conditions, and it has been held that a similar difference might explain some of the differences between the findings of Hill and Rahimtulla (1965) and those of Scopes and Ahmed (1966). Comparisons using the *effective temperature* scale devised by Houghten and Yaglou in 1923 tend to support such a view. However, this early attempt to compare different thermal environments on a single numerical scale as a result of a series of subjective tests on adult men overemphasized the importance of humidity (Yaglou, 1949).

We have used an apparatus similar to that of both Hill and Scopes and covered a wider range of humidity than either of them. Only small changes in heat balance were found following changes in humidity. The observed differences could at the most account for a change of only 1° C. in the predicted critical temperature. It is probable that the much larger discrepancies actually reported result from different methods of assessing environmental temperature. A knowledge of mean radiant temperature, mean air speed and temperature, and posture are all essential to any uniform interpretation of results.

Silverman and Blanc (1957) showed that the use of high humidity significantly reduced the mortality of premature infants nursed in incubators with an air temperature of 28–29° C. They noted higher rectal temperatures in those infants nursed at high humidity, and speculated that this might be the cause of the decreased mortality. Silverman, Fertig, and Berger (1958) showed subsequently that mortality was indeed reduced when infants were nursed in incubators at 31–32 instead of 28–29° C. Miller *et al.* (1961) also demonstrated how increasing humidity increased the body temperature of small premature babies nursed in incubators with an air temperature of 31–32° C. without noticeably altering oxygen consumption. More recently, Silverman, Agate, and Fertig (1963) showed that mortality was not affected by a relative humidity of 80–90% instead of 45–55% when infants were nursed in a radiant environment which maintained abdominal skin temperature at $36 \cdot 1 \pm 0 \cdot 1°$ C.

Our present results are in keeping with these earlier findings. They suggest that when infants are nursed at a temperature below the thermoneutral range, lowering the relative humidity increases heat loss. However, over the range of humidity that can be achieved in modern commercial incubators without auxiliary equipment (Bardell, Freeman, and Hey, 1968), the effect on heat loss is not large, and more than half of it can be accounted for by changes in evaporative heat loss from the respiratory tract. Yet, though the increase in heat loss is not large, and though heat production usually increases, this increase is not normally enough to balance the increased loss. Body temperature falls in consequence. The lowered body temperature, increased oxygen consumption, and raised calorie demands may well account between them for the increased mortality observed in premature and sick infants. However, when infants are nursed in a neutral thermal environment and body temperature is normal, adjustment in the degree of vasodilatation appears to counteract any change in heat balance caused by a moderate change of humidity. Further work would be necessary to demonstrate if this is completely true following large changes in humidity. Sweating will also occur in full-term infants once the rectal temperature rises above normal. This will also tend to counteract any change in heat balance.

Summary

The effect of changes in the relative humidity of the air on the total heat production and heat loss of healthy naked full-term babies has been studied

at 35° C. (a thermo-neutral environment) and at 31° C. (a temperature below the thermo-neutral range), by indirect calorimetry. At 31° C. (88° F.) lowering the humidity by 25 or 63% significantly increased total heat loss; heat production also increased but not enough to match the increased loss. The effect was not large: a change from 85 to 22% humidity increased mean total heat loss from 42·4 to 47·5 cal./kg. min. At 35° C. (95° F.), in contrast, no effects on heat production could be detected following a 29% change in humidity; neither could any change in heat loss be detected once rectal temperature exceeded 36·8° C. It is suggested that this difference is due to the compensatory regulation of body temperature achieved by vasodilatation in the thermo-neutral temperature range.

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