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Head insulation and heat loss in the newborn

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SUMMARY The thermal balance of 13 term infants was measured in a closed-circuit metabolism chamber. Each was studied naked, then with a gamgee-lined hat, and finally with a 'cummerbund' made of a similar material and of similar dimensions. At 27°C the oxygen consumption of the 'hatted' babies was only 85% and the total heat loss 75% of the values measured with the infants naked. The cummerbund offered no detectable benefit. An additional 10 infants were studied while wearing a tubegauze hat at environmental temperatures of 28·5 (±0·5)°C. This type of hat gave no measurable thermal protection. It is concluded that a substantial reduction of thermal stress in adverse environments can be achieved simply and cheaply by adequately covering the vault of the skull.

The brain of the newborn infant uses a large proportion of the total oxygen consumption ($\dot{V}O_2$)[1 2] and therefore generates much of the total heat he produces. Due to the fairly high cerebral blood flow, it is likely that most of this heat would be transported to the body, but as the surface area of the head represents 20·8% of the total body surface area,[3] heat losses from the head must represent a substantial proportion of the whole. It is to be expected that if the head were insulated by the provision of a hat, heat loss would be lessened, as would be the dangers of hypothermia.

Although Aikens[4] failed to show any difference in the rate of rectal temperature change in the first hour after birth between babies with and without a tubegauze hat, Chaput de Saintonge *et al.*[5] showed that a gamgee-lined woollen hat gave appreciable thermal benefit in the first 30 minutes of life. In both studies the rate of change of rectal temperature was the only measured index of thermal behaviour.

The aims of the present study were to assess more fully the diminution in heat losses when a gamgee-lined hat was applied, and to compare this with protection by a pad or cummerbund of similar materials covering a similar area of the lower abdomen. In addition, 'paired' studies of infants naked then wearing a tubegauze hat, similar to those described by Aikens, were undertaken to assess the efficacy of such insulation.*

Methods

All the studies were performed on well infants from the maternity wards of the London Hospital.

*A preliminary communication was presented to the Neonatal Society in February 1978.

Table 1 *Details of the infants studied*

Study	*Gender*		*Weight (kg)*	*Age (days)*
	Boys	*Girls*		
Gamgee hat and cummerbund				
(n=13)	6	7	3·16	5
Range			(2·76–3·66)	(2–6)
Tubegauze hat (n=10)	6	4	3·29	4
Range			(2·85–3·82)	(2–6)

Measurements were undertaken only after the informed consent of the mother had been obtained; generally she was present at some time during the study of her baby. Details of the infants are given in Table 1.

The infants were nursed prone in a closed-circuit metabolism chamber, as described by Hill and Rahimtulla[6] and modified by Hey and Katz.[7] In the gamgee-lined hat infants, attempts were made to measure each infant at 3 environmental temperatures when naked, and then with abdominal or head protection. Minute-by-minute records of behavioural states, based on the criteria of Prechtl and Beintema,[8] were made by an experienced observer continuously watching the infant for body and eye movements. Because of the influence of sleep,[9] position,[10] feeding,[11] and activity on $\dot{V}O_2$, the following criteria had to be met for inclusion in the final analysis: (1) All measurements were made in 'quiet' rapid eye movement sleep. (2) At least 8 minutes of continuous recording were required. (3) Traces made during periods in which the infant made more than one gross body movement in any one minute were excluded. (4) Maintenance of a reasonably constant body position during the observations was required.

(5) Only measurements made at least one hour after the end of a feed were included.

Because of these strict criteria, paired comparisons proved impossible to obtain and only 23 observations of the infants when naked, 20 when hatted, and 11 wearing a cummerbund were used in the final analysis.

In order to calculate the area covered by the hat, the surface area of the head was assumed to represent 20·8% of the total body surface area, calculated using Boyd's formula.[12] Initially, the shape of the head was thought of as a sphere, the maximum circumference being the occipito-frontal circumference (OFC) of the head. Accordingly, the OFCs and weights of 15 infants were carefully measured. When the surface of the head, calculated from the weight of the infant, was compared with the area of the sphere, calculated from the OFC, there was a significant difference ($P<0·001$), the spherical area being some 20% less.

The surface area of a cylinder, less one end, was then considered, using a brow-chin length as the height (an underestimate) and the OFC as the circumference (an overestimate). The values obtained conformed more closely with the values calculated using the weight-surface area formula ($P<0·05$), the mean difference being $-3·6$%. The area left exposed after fitting the hat was then measured horizontally, that is around the face, and vertically. These measurements enabled an approximation of the portion exposed to be calculated. This was found to represent 25% (SD $\pm$ 3·6) of the total surface area of the head. The appropriate area of abdominal padding, in the form of a rectangle, was therefore 75% of the surface area of the head.

In all instances rectal temperatures were recorded; where possible, skin temperatures were also recorded, but if skin thermistors became detached, mean skin temperature was calculated using the formula derived by Clark and Stothers.[13]

The operative environmental temperature was calculated from air and wall temperatures weighted according to Gagge's formula.[14] During each period, minute-by-minute measurements from the traces provided the data for a FORTRAN program written to calculate a mean $\dot{V}O_2$, standard deviation and standard error in millilitres of oxygen per kilogram per minute, corrected to standard temperature and pressure, dry. It was assumed that one litre of oxygen was equivalent to 4·83 kcal. The potential errors in using this figure have been fully discussed by Karlberg.[15]

From the $\dot{V}O_2$ and heat storage values, calculated from the rectal and skin temperature changes, the total heat loss was obtained. The total evaporative loss was calculated by subtracting the saturation of the inflowing air from the outgoing. Total insulation was then computed using Hey's formula.[16] All of the formulae used are given in full in the appendix.

The effective surface area, that is the area concerned in insensible heat loss, was calculated by assuming 3 'standard' positions: crouched, mid, and stretched, rendering this area 30, 25, and 20% less than the total.[10]

A linear relationship between the variables and the rectal-environmental temperature was assumed, permitting a linear regression to be performed in each case. The equation expressing the relationship is expressed in the form $y = A + Bx$, where A is the intercept on the 'y' axis, and B the slope value of the line. Comparisons of the slopes and intercepts were made using Snedecor's formula.[17]

In the infants wearing tubegauze hats, the same criteria for inclusion were imposed, the same analytical methods used, but readings, naked then hatted, were made at only one environmental temperature (28·5°C $\pm$ 0·5). Related *t* tests were then performed.

Results

Head and abdominal (gamgee) insulation

Oxygen consumption

The results of linear regression of $\dot{V}O_2$ against rectal-environmental temperature difference (T_{r-e}) are shown in Fig. 1. The calculations do not include data obtained when T_{r-e} was less than 5°C, as no diminution in $\dot{V}O_2$ would be expected after entry into the thermoneutral range.

Statistical comparison of the slopes (B values) showed no significant difference between the naked and the abdominal pad groups; the hatted infants' values were significantly lower ($P>0·01$) than either.

Values of $\dot{V}O_2$ calculated from the regression equations when the rectal-environmental temperature difference was 10°C were 7·05 and 8·24 ml/kg per min for the hatted and naked babies respectively; the insulation was therefore associated with a saving of 14·5% in $\dot{V}O_2$.

In addition, linear regression performed with values from the hatted group at rectal-environmental temperature differences of greater than 6·5°C showed the slope value (0·379) to be insignificantly different from that of the naked babies when the difference was greater than 5°C ($F = 2·19$, df = 1, 27 $P>0·05$), suggesting that the protection offered by the hat reduced the lower limit of the thermoneutral range by some 1·5°C.

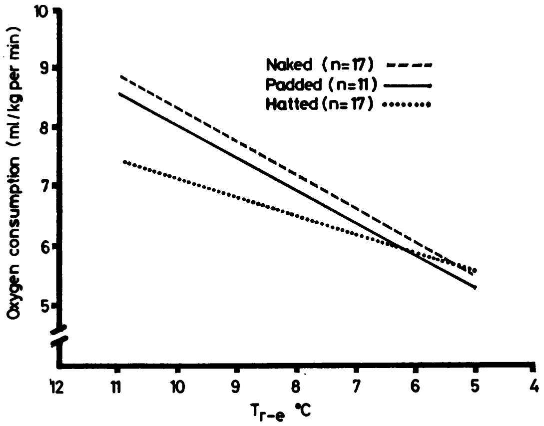

Fig. 1 *Linear regressions of the $\dot{V}o_2$ of the three groups plotted against the rectal-environmental temperature difference. In all cases the regression coefficients are significant at the 1% level. The respective equations for the naked, hatted, and padded groups are:*
$\dot{V}o_2 = 2{\cdot}72 \pm 0{\cdot}551(T_{r-e})$, $\dot{V}o_2 = 4{\cdot}08 \pm 0{\cdot}297(T_{r-e})$, and $\dot{V}o_2 = 2{\cdot}57 \pm 0{\cdot}544(T_{r-e})$. In calculating the values, data from infants nursed in thermoneutrality ($T_{r-e} < 5°C$) are excluded (see text).

Heat storage
Only the naked group had a significant correlation coefficient, when heat storage values were regressed against T_{r-e}, rendering statistical comparison invalid although the hatted group had the lowest slope value.

Nonevaporative heat loss
As no restrictions were imposed on the lower limit of rectal-environmental temperature difference, 23 observations were made of the naked infants, 20 with hats, and 14 with abdominal padding. Linear regressions of the values in each of the groups all had significant coefficients ($P<0{\cdot}01$). Statistical comparison of the slope values (naked 3·49, hatted 2·11, and padded 3·61) showed the only significant difference to be between the hatted infants and the other two groups ($P<0{\cdot}01$ in each case). The calculated nonevaporative heat losses at a rectal-environmental temperature difference of 10°C was 28·6, 36·96, and 37·14 W/m² for the hatted, naked, and padded groups respectively, the hat therefore being associated with a reduction of dry heat loss of 23%.

Evaporative heat loss
No significant linear correlation was found with evaporative heat loss and rectal-environmental temperature difference. The overall trend in each of the three groups was for heat loss to diminish with increasing temperature being 7–8 W/m² in the thermoneutral zone, and 5·6 W/m² in cooler environments.

Total heat loss
Fig. 2 illustrates the relationships between the three groups.

The results of statistical comparison of the slopes are shown in Table 2.

The calculated loss when naked, at a rectal-environmental temperature difference of 10°C, was 42·4 compared with 33·9 W/m² when hatted under the same circumstances. The hat therefore saved 25% of the total heat lost when the environmental temperature was 27°C, assuming a rectal temperature of 37°C.

Thermal insulation
The total insulation of the three groups was calculated, although the results must be treated with

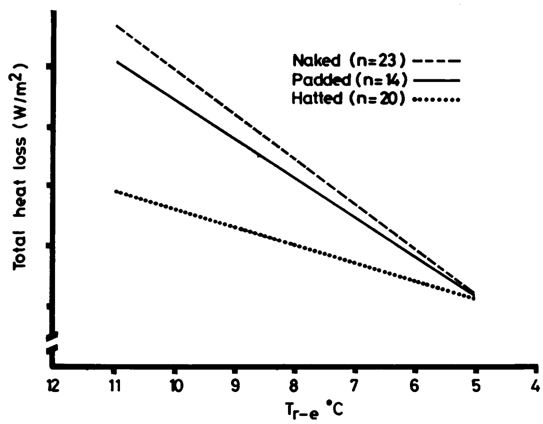

Fig. 2 *Linear regression of the total heat loss of the three groups plotted against rectal-environmental temperature difference. As with $\dot{V}o_2$, all of the regression coefficients are significant at the 1% level. The respective equations for the heat loss (W/m²) of the naked, hatted, and padded groups are $8{\cdot}45 \pm 3{\cdot}39(T_{r-e})$, $17{\cdot}03 + 1{\cdot}69(T_{r-e})$, and $12{\cdot}02 + 3{\cdot}23(T_{r-e})$.*

Table 2 *Comparison of the linear regression of total heat loss against T_{r-e} slopes, using Snedecor's method,[17] shows that the pad confers no thermal benefit, and that hatted infants lose significantly less heat than either of the other two groups*

	F value	*Degree of freedom*	*Significance*
Hat: naked	26·356	1,39	<0·01
Pad: naked	0·046	1,33	NS
Hat: pad	6·185	1,30	<0·01

Table 3 *Results of 'paired' studies of infants naked and wearing a tubegauze hat*

	Naked	*Gauze hat*
Dry heat loss (W/m ²)	28·40 (3·64)	30·64 (2·94)
Evaporative heat loss (W/m ²)	7·48 (1·63)	6·84 (1·68)
Total heat loss (W/m ²)	35·88 (3·71)	37·48 (3·06)
Total insulation (°Cm²/W)	0·190 (0·015)	0·193 (0·012)

some reserve. As already stated, some calculations include a calculated mean skin temperature. Again, the regressions do not include data obtained when T_{r-e} was less than 5°C. The correlation coefficients of the naked, hatted, and padded groups were somewhat poorer than in the previous partitional calculations ($r \simeq 0·05$ in each case). However, from the equations, the total insulation when naked with a rectal-environmental temperature difference of 10°C would be 0·192°C W/m², and with a hat 0·233°C W/m², an increase of some 21%.

Gauze hat series

Mean values (with standard deviations) of the 10 infants studied naked, then wearing tubegauze hats are given in Table 3. The tubegauze hat would appear to be associated with an insignificant increase in total insulation of only some 2%.

Discussion

Consideration of the results of studies of the gamgee hatted infants raises two interesting physiological points. The $\dot{V}O_2$ of the infants wearing a hat was 14·5% less than that of the naked group at an environmental temperature of about 27°C. If the head represents 20·8% of the total surface area and 75% of this is covered by the hat, then the portion exposed will be 15·6% of the total body surface area. The obvious similarity between the percentage covered and the percentage decrease in $\dot{V}O_2$ supports the suggestion that there is a fairly direct relationship between the area exposed to cooling and the $\dot{V}O_2$, or chemical response. That this should be true of the head is in contrast to the suggestion of Froese and Burton[18] that it was not a particularly thermosensitive area in the adult. This was based on the observation that we may expose our heads to a cool environment without feeling cold, a point which they felt was supported by Burton's finding[19] that the head has a fairly high and constant skin temperature, and that the arterial supply to the forehead is little affected by cooling. Burton's temperature measurements were also made on the forehead, an area unique in its nervous supply, and perhaps unrepresentative of the rest of the head in its thermal response.

The apparent absence of effect of lower abdominal insulation was almost certainly due to two factors. With the infants nursed prone, only the lower back was 'protected', although it must also be noted that a portion of the 'hatted' head would be further insulated by contact with the mattress. It has been demonstrated thermographically[20] that the lower trunk is not one of the hotter areas of the body, having no underlying thermogenic organs, and would consequently lose less heat than an area such as the head. In addition, inter-infant variability would mask minor differences, especially in a fairly small series.

Respiratory calorimetry renders thermal balance calculations highly dependent on changes in heat storage and evaporative losses. The strict criteria used in the final analysis—such as sleep state, position, postprandial state, and absence of movement allowed only short periods of observation. Transient fluctuations in rectal temperature or water loss may well have been responsible for the lack of correlation of these variables. The effect of the hat on mean skin temperatures is unknown, but must be considerable. Similarly, the effect of the hat on evaporative losses is not predictable. However, the total calculated heat losses appear reasonable. The naked infants, in thermoneutrality, had an evaporative heat loss of about 7 W/m² representing 27% of the total heat loss of 25·5 W/m². This figure is only slightly higher than that found by Hey and Katz[7] of 23%. The higher $\dot{V}O_2$ values recorded in their series, due possibly to movement, etc., probably account for the decreased ratio.

The clinical importance of these findings is obvious. Hypothermia is still common during the neonatal period. Apart from accidental hypothermia associated with the actual birth, surgical and investigative manoeuvres often necessitate fairly extensive and prolonged exposure; low rectal temperatures are common after such procedures. A tubegauze hat offers little protection, but heat loss can be substantially reduced by covering the vault of the skull with a gamgee-lined woollen hat.

Appendix

Formulae used in the various calculations.

Surface area [12](A)

$A = 4·688 * W^{(0.8168-0.01541gW)} * 10^{-4}$

when A is in m², and W the weight of the infant in grams.

Mean skin temperature[13] ($T_{\bar{s}}$)

$T_{\bar{s}} = 36·03 - 0·203 * (T_r - T_e)$

when $T_{\bar{s}}$ is in °C as are the rectal (T_r) and environmental (T_e) temperatures.

Operative environmental temperature[14] (T_e)
$T_e = 0{\cdot}4\ T_a + 0{\cdot}6T_w$
when T_e is in °C as are the air (T_a) and wall (T_w) temperatures.

Heat storage[16] (HS)
$HS = W((0{\cdot}7\triangle T_r) + (0{\cdot}3\triangle T_{\bar{s}}))^*\ 3{\cdot}47$
when HS is in watts, W is the weight of the infant in kg, $\triangle T_r$ and $\triangle T_{\bar{s}}$ are the rectal and mean skin temperature changes in °C hour, and 3·47 is the specific heat of the body[21] in kJ/kg °C.

Total insulation[15] (I) = tissue insulation (I_t) + ambient insulation (I_a)
$I_t = A(T_r - T_{\bar{s}})\ H_{CR} + H_{Es}$ and $I_a = A(T_{\bar{s}} - T_e)/H_{CR}$
when I_t and I_a are in °C m^2/W, A is the surface area in m^2, T_r, T_e, and $T_{\bar{s}}$ are the rectal, environmental, and mean skin in °C. H_{CR} is the 'dry' heat loss and H_{Es} the evaporative losses, both in watts.

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