Regional heat loss in newborn infants

Part I. Heat loss in healthy newborns at various environmental temperatures

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Summary

In 17 newborn infants (gestational age 33 - 40 weeks, birthweight 1 100 - 5 560 g) heat flux (HF) from the forehead, chest and calf was measured by HF transducers and heat loss (HL) from those body regions was calculated, taking into account variations in surface area. Both HF and HL were related to operative environmental temperature (\(T_{op}\)). Average HF from the forehead, chest and calf was 63,3, 51,5 and 45,7 W/m\(^2\) respectively at a \(T_{op}\) of 31,2°C and increased by 100%, 66% and 50% as the \(T_{op}\) fell to 27,5°C. HL from the head, trunk and limbs contributed about one-third each to total dry HL.

These data, in the form of regression equations, permit assessment of heat loss from the various body regions of individual neonates in any thermal environment.

Subjects and methods

Seventeen randomly selected neonates were studied in incubators (Isollette Infant Incubator, model 86 C; Airshields (UK) Ltd, Essex). The mean gestational age (± SD) was 35,6 ± 2,2 weeks (range 33 - 40 weeks). The mean weight at the time of the study was 2 147 ± 1 024 g (range 1 100 - 5 560 g), the mean age 5,5 days (range 1 - 25 days) and the mean rectal temperature 36,7 ± 0,29°C (range 36,2 - 37,3°C). The infants were free from cardiovascular, respiratory or cerebral disease. Their head circumferences were normal (range 27 - 37 cm). Parental consent was obtained.

The HF from the body surface was measured by means of HF transducers (Thermonetics, San Diego, California, USA). These transducers, 20 x 10 x 1 mm in size, produce an electrical signal which is proportional to the heat flow per unit area and time. For each transducer a calibration constant describing how much HF is required to produce 1 mV is provided by the manufacturer. To check the calibration constant and accuracy of the transducers we designed a calibration device similar to the one described by Gin et al.\(^{13}\) consisting of a copper block containing an electrical heating device. The transducer to be calibrated is attached to the surface of this block with thin double-adhesive tape. The heat produced passes via the surface of the block (and via the transducer) into the environment, a heat sink. An even distribution of temperature and HF is ensured by the extremely high conductivity of copper. Under steady-state conditions the heat released from the electric heater will equal heat flow through the surface boundaries of the copper cylinder. The heat flow per unit area and time can then be determined from the heat produced (i.e. product of voltage across and current through the heater) and the surface area of the copper block. This heat flow is related to the voltage signal produced by the transducer and measured by a sensitive voltmeter. We found that all transducers had an accuracy better than 5% (calibration HF v. HF derived from calibration constant and voltage output) and a linear response up to at least 300 W/m\(^2\). Their voltage output during the study was amplified and recorded on a Beckman R611 polygraph.

The net HF from an infant's body surface is affected by conductive and radiative heat exchange with the environment. Consequently the thermal environment inside the incubator had to be described by an operative environmental temperature (\(T_{op}\)) which takes into account both components responsible for heat exchange, namely the temperatures of the incubator walls and the incubator air. In a previous study we determined an approximate \(T_{op}\) from the incubator air and study room temperatures and related it to a temperature which was thought to be the true or 'criterion' \(T_{op}\) as it was determined from the temperatures of the 6 incubator areas and the incubator air. The results showed a close relationship between the criterion and approximated temperatures (Fig. 1). In this study the true \(T_{op}\) was obtained by determining the approximate \(T_{op}\) from the measured incubator air and study room temperatures and correcting it according to the known relationship (Fig. 1).
Fig. 1. Relationship between the criterion $T_{op}$ (6 incubator areas and incubator air) and the approximated $T_{op}$ (using only the incubator air temperature and room temperature). Temperatures in incubators next to the window (e) and next to the inner wall (q) of the study room are indicated.

The incubator air temperature was measured by a thermistor (Yellow Springs Instruments, 420 series) positioned in the middle of the incubator 15 cm below the ceiling wall. The thermistor was accurate to 0.1°C and linear over the temperature range studied.

In order to know how the surface area of the head, trunk and extremities varied with body weight, we investigated 11 neonates weighing between 960 and 4750 g by the segment-zone approach as described by Katch and Weltman. The body was viewed as consisting of 14 segments, a sphere representing the head and cylinders representing the trunk, the upper and lower parts of the arms and legs, and the hands and feet. The surface of the head was calculated from the average fronto- and mento-occipital circumference and the surface of the cylinders from the girth and circumference of the respective body part. The calculated surfaces of the head, the trunk and the extremities were expressed as percentages of the total body surface and related to body weight as follows:

% head surface v. weight: $y$ (%) = 24.8 - 1.53x (kg);
$r = 0.81; P < 0.005$

% trunk surface v. weight: $y$ (%) = 35.9 + 0.20x (kg);
$r = 0.16; NS$

% extremities surface v. weight: $y$ (%) = 39.2 + 1.32x (kg);
$r = 0.67; P < 0.05$.

Protocol

Fifteen infants were studied at one temperature, 1 was studied with the temperature raised and 1 was studied with the temperature lowered. They were all studied between feeds, lying naked in the supine position and at rest. Special care was taken to ensure that they were lying at a fixed distance from the end of the incubator, where the heated air enters the dome. They were all in thermal equilibrium.

One HF transducer was fixed to the forehead, one to the chest between left nipple and the xyphoid, and one to the medial side of the calf between the knee and the ankle. The transducers were attached with double adhesive tape and secured in position with a thin paper tape which would have a negligible insulation effect. Each study lasted for at least two heating cycles of the incubator (about half an hour).

Analysis of data

Each record obtained during the course of the 19 studies was analysed to obtain an average of 10 data sets (range 5 - 15 sets) of HF (W/m²) and $T_{op}$. The amount of heat lost in each region was calculated from the HF and the corresponding surface area (see above). We assumed that HF from the forehead, chest and calf was representative of that from the head, trunk and extremities respectively. The regional HL was then expressed as a percentage of total (dry) HL (being the sum of HL from the head, trunk and extremities). Linear regression analysis was used for statistical analysis.

Results

Forehead, chest and calf (Figs 2-4)

The average HF from the forehead, chest and calf was 63.3, 51.5 and 45.7 W/m² respectively at a mean $T_{op}$ of 31.2°C. With decreasing temperature the HF from all three body sites increased, this increase being highest at the forehead and lowest at the calf. When the $T_{op}$ fell from 32.0 to 27.5°C HF from the forehead increased by 100% while that from the calf increased by 50%. HF always increased linearly in individual infants subjected to two temperature levels (Fig. 5) as well as in the whole group studied at a temperature range of about

Fig. 2. HF from the forehead in relation to $T_{op}$. The 95% confidence limits are depicted.
Regional HL related to total HL (Figs 6-8)

The average HL from the head, trunk and extremities was 25.8%, 36.6% and 37.4% respectively of total HL at a mean Top of 31.2°C. With decreasing temperature the percentage heat loss from the head and chest increased while that from the extremities decreased (Figs 6-8, Table I). At 27.5°C HL from the head was 28%, that from the chest 38% and that from the limbs 34% of the total.

Discussion

Several studies have evaluated the contribution of dry and wet HL to total HL at various temperatures. The insensible water loss and sweating in various body regions in relation to environmental temperature have also been measured using an evaporimeter. In our study we determined regional HLs and their contribution to total dry HL. The results demonstrate a considerable difference in regional HF at a mean operative Top of about 31°C, which increases as the environmental temperature falls to about 27°C. The most striking finding was that HL from the head increased faster than that from any other part of the body, and that it did so in a linear fashion. Both facts suggest that the head has no or a very limited

| TABLE I. RELATIONSHIP OF REGIONAL HF AND HL TO T_\text{op} °C (N = 226) |
|----------------------|----------------------|----------------------|
| HF (W/m²)               | Regression equation y = ax + b | SE of y interc. SE of slope |
| Forehead                | -0.92*               | y = 470.2 - 13.0x    | 11.4 0.36 |
| Chest                   | -0.94*               | y = 321.4 - 8.6x     | 6.5 0.21 |
| Calf                    | -0.75*               | y = 244.9 - 6.4x     | 11.7 0.37 |
| HL (%)                  | -0.23*               | y = 42.7 - 0.54x     | 4.7 0.15 |
| Head                    | -0.13**              | y = 45.6 - 0.29x     | 4.7 0.15 |
| Trunk                   | 0.26*                | y = 11.4 + 0.84x     | 6.4 0.21 |
| Limbs                   |                       |                       |          |

*p < 0.001; **p < 0.05.
Froese and Burton\textsuperscript{17} measured dry HL from the head by means of a calorimeter in adults and Stothers\textsuperscript{10} by means of HF discs in newborns. Stothers did not specify the extent to which cranial HF depended on environmental temperature. According to our data head HL of newborns at low environmental temperatures is considerably higher than in adults\textsuperscript{17} as
judged by the slope and y-axis intercept of the regression equations relating HL to environmental temperature (slope 12.2 v. 7.7, y intercept 440 v. 150 W/m²). If a brain temperature of 37°C is assumed, the total insulation of the head can be calculated according to the formula:17

\[ I = I_1 + I_2 \times T_{\text{brain}} - T_{\text{ambient}} + 5.5, \]

where \( I \) = insulation of head, \( I_1 \) = insulation of skin. According to our results total insulation of the head was 0.5 clo and thus less than in adults (0.74 clo).18

In addition, the insulation of the head would not change in newborn infants over the temperature range studied (0.5 clo at 32°C and 27°C) as it would in adults.17

In consequence, at low temperatures head HL can amount to one-third of total HL (dry)

HF in individual infants and in the group as a whole points towards the fact that the skin represents only one-fifth of the body area. Our results are in full agreement with and an explanation of the findings of Stothers11 that oxygen consumption could be reduced by 14% in neonates covered with a gamelle hat and of Glass et al.19 demonstrating a retardation of head growth in neonates kept at low environmental temperatures. One speculates whether this lack of head insulation in newborns allows the thermal environment directly to influence metabolism and circulation of and thermoregulatory centres within the brain.

HF from the calf was less overall and its increase with decreasing temperature less than that from the head or chest. Physical thermoregulatory mechanisms bringing about tissue insulation by decreased peripheral blood flow and vasoconstriction in the skin might be responsible for this.18 Skin temperatures would have to be measured in order to determine the exact change in insulation. However, the linear increase of calf HF in individual infants and in the group as a whole points towards the fact that the insulating capacity of the limb did not increase efficiently with cooling. Although the hands and feet were shown to decrease their HL when the environmental temperature fell to 27°C or 25°C, their capacity to conserve heat would have little effect because they constitute only about 10% of the body surface.11,12 The contribution of a body part (or region) to total dry HL becomes more a function of the HF density prevailing there at low temperatures and of the surface area it represents at high temperatures.

Our data on regional HF and surface areas permit assessment of the amount of heat lost from the head, trunk or limbs in individual neonates in any thermal environment. Furthermore, measuring regional HF with HF transducers and insensible water loss with an evaporimeter could be developed into an alternative method for assessing total energy loss.

REFERENCES


News and Comment/Nuus en Kommentaar

Pleural lesions in asbestos workers

The classic radiological picture of asbestosis is that of a slowly developing pulmonary fibrosis. Another characteristic is the changes in the pleura, with fibrotic or calcified plaques, a pleural effusion, or eventually the development of a mesothelioma.

Lemenege et al. (Presse Med 1985; 14: 1462) report on the pleural changes and their relation to lung function in 380 subjects working in an asbestos factory. The mean age of the study group was 47 years, and they had been exposed to asbestos on average for 20 years. Of the entire sample 127 (33.4%) showed pleural thickening either bilaterally or unilaterally, diffuse or circumscribed. Eleven had pleural calcifications and 29 obliteration of the costophrenic angle. Only 14 had any signs of pulmonary asbestosis and then usually only to a minor degree.

It would seem that a pleural effusion appearing during the first 20 years of exposure is very likely to be benign, whereas pleural changes taking place later may suggest a mesothelioma or a pulmonary cancer.

The authors note that the pleural lesions had a restrictive influence on respiratory function in 24% of the cases and also that small-airways obstruction was detected by flow volume loops in 9% of those subjects who were non-smokers but showed pleural thickening. They suggest that patients with a pleural effusion and obstructive airways disease may well have an underlying pulmonary asbestosis, particularly if they are non-smokers.