Air temperature recordings in infant incubators

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Aynsley-Green, A., Roberton, N. R. C., and Rolfe, P. (1975). *Archives of Disease in Childhood*, 50, 215. **Air temperature recordings in infant incubators.** Air temperatures were continuously recorded inside four incubators with proportional heating control and six incubators with on/off heating cycles, during routine use. The air temperatures in the former were constant throughout, with a gradient between the roof and above-mattress air temperature not exceeding 1°C. In contrast, the recordings from the latter models showed a regular cyclical oscillation, the duration of the cycle varying from 14 to 44 minutes. Each incubator had a characteristic profile. The roof air temperature could vary by as much as 7.1°C and the above-mattress air temperature by as much as 2.6°C during the cycle. The oscillation persisted in the air temperatures recorded inside an open-ended hemicylindrical heat shield when used inside these incubators, but was markedly reduced inside a closed-ended heat shield. Carbon dioxide concentration did not increase significantly inside the latter.

Careful control of the ambient temperature and the provision of adequate warmth have increased the survival of preterm infants (Silverman, Fertig, and Berger, 1958; Jolly, Molyneux, and Newell, 1962; Day *et al.*, 1964). However, the use of incubators to provide such an environment is not without risk. Perlstein, Edwards, and Sutherland (1970) showed that the incidence of apnoeic spells in preterm infants increased during sudden changes in incubator air temperature, while Yashiro *et al.* (1973) suggested there was an increased mortality rate in infants nursed in higher incubator temperatures.

Oscillations in air temperature occur in incubators warmed by forced air convection (Gleiss, 1956; Agate and Silverman, 1963; Perlstein *et al.*, 1970), though manufacturers of incubators of more recent design have attempted to overcome this problem by incorporating a proportional control system for the heating unit together with changes in air-flow profile. There have been no studies reporting the performance of these latter incubators during routine use.

Heat shields are widely used inside incubators in order to reduce radiant heat loss from the infant (Hey and Mount, 1967), but it is not clear whether sudden changes in air temperature still occur inside

the heat shield when used within incubators known to produce oscillations in air temperature.

We have examined air temperature gradients inside two commonly used types of incubator and inside two types of heat shield.

Methods

Six incubators with on/off heating cycles (Incubator A) and four incubators of more recent design with proportional control heating units (Incubator B*) were studied during routine use before and after occupancy by preterm infants. Empty incubators were allowed to warm to a steady state for 6 hours, the temperature controls having been set for routine use by the nursing staff. Humidity was not added and the incubator doors were not opened during the recording periods. Incubator air temperatures were measured 7 cm from the roof, 3 cm above the mattress, and at a point equidistant between the two by thermocouple probes suspended through the access hole in the roof. A six-channel Ellab† type Z-94B electric thermometer was used to record the temperatures, the channels being sequentially sampled every 4 seconds.

The incubators were then studied when occupied by preterm infants with heat shields *in situ*. The incubator temperature control was set by the nursing staff appropriate to the infant's age and weight from the data of Hey and Katz (1970). Rectal, wrist, ankle, and

*Vickers Medical Ltd, Basingstoke, England.

†Ellab Ltd., Copenhagen.

great toe temperatures were recorded using Ellab NR-7, NH-3, and NAP 1 thermocouple applicators, respectively. Incubator air temperatures were measured 7 cm from the roof and 5–7 cm above the infant's abdomen inside the heat shield. Servo control was not used.

Two types of heat shield were used. The first consisted of an open-ended hemicylinder of clear perspex (Fig. 1); the second was a perspex box with one end occluded and large enough to enclose a preterm infant (Fig. 2). The carbon dioxide concentration within the incubator and inside the closed-ended heat shield was measured by means of a Beckman CB1 Medical Gas Analyser.*

Results

Air temperature changes in empty incubators. A recording obtained from a type B

FIG. 1.—An open-ended hemicylindrical heat shield in situ. The servo control probe attached to the infant's abdomen was not used during the study.

FIG. 2.—A closed-ended heat shield. The servo control probe attached to the infant's abdomen was not used during the study.

*Beckman Instruments, Palo Alto, California.

incubator with proportional heating control is shown in Fig. 3. Similar recordings were obtained from all four incubators. The air temperature is constant throughout with a gradient of 0.5°C . between the roof and above-mattress temperatures. None of the incubators had a gradient greater than 1°C .

In contrast, the air temperatures inside the type A incubators with on/off heating cycles showed regular cyclical variations, with a wide gradient between the roof and above-mattress temperature (Fig. 4). Each incubator had a characteristic profile. During the thermal cycle the area immediately above the mattress was always the coldest part of the incubator. The difference between the

FIG. 3.—Air temperature recordings in an incubator with proportional control. A gradient of 0.5°C exists between the temperature measured 7 cm from the roof (Top) and 3 cm above the mattress (Bottom). The temperature recorded at a point equidistant between the two (Middle) is superimposed upon the roof temperature. Time scale: 4 min/division.

FIG. 4.—Air temperature recordings in an incubator with an on/off heating cycle. A regular cyclical oscillation in air temperature occurs with a varying gradient between the recording points 7 cm from the roof (Top), 3 cm above the mattress (Bottom), and at a point equidistant between (Middle). Time scale: 4 min/division.

TABLE

Air temperature measurements in 6 incubators with on/off heating cycles showing duration of thermal cycle together with difference between the roof and above-mattress air temperatures at the hottest (peak) and coolest (nadir) parts of the cycle; and amplitude of temperature oscillation during thermal cycle at roof and above-mattress recording positions

Incubator number	Thermal cycle (min)	Roof-above mattress temperature difference (°C)		Temperature difference during thermal cycle (°C)	
		Peak	Nadir	Roof	Above mattress
1	44	5.7	1.2	7.1	2.6
2	40	4.0	2.8	2.7	1.5
3	36	1.5	1.0	1.5	1.0
4	20	1.8	0.7	2.8	1.7
5	14	1.5	0.9	1.5	0.9
6	14	3.1	2.2	1.4	0.5

above-mattress air temperature and the roof air temperature ranged from 1.5 to 5.7°C when the incubators were at the hottest part of the cycle, and between 0.7 and 2.0°C when the incubators were coolest. Marked temperature swings occurred at all the recording points during the thermal cycle. These were maximal in the air temperature at the roof and minimal just above the mattress. At the roof, the air temperature could vary by as little as 1.5°C, or as much as 7.1°C in different incubators. The corresponding values for the midpoint of the incubators were 0.5 and 6.6°C, and for the above-mattress temperature 0.5 and 2.6°C (Table).

Air temperature changes inside heat shields.

Fig. 5 and 6 show temperature recordings obtained from a 1200 g preterm infant within a type A incubator, and the air temperature recorded inside an open-ended and closed-ended heat shield, respectively.

FIG. 5.—Air temperature recordings inside an open-ended heat shield within an on/off heating cycle incubator. The 'incubator air' temperature was measured 7 cm from the roof, and that inside the heat shield 3–5 cm above the infant's abdomen. The infant's rectal, wrist, ankle, and great toe temperatures are also shown. Time scale: 4 min/division.

tively. The cyclical change in air temperature is present inside the open-ended heat shield but is virtually nonexistent inside the closed shield, though the mean air temperature is slightly lower inside the latter. Similar recordings have been consistently obtained from the heat shields when used within all the incubators of this type.

FIG. 6.—The same temperature measurements in the previous figure were recorded with the infant inside the closed-ended heat shield. Time scale: 4 min/division.

Carbon dioxide concentration inside the closed-ended heat shield. No increase in CO₂ concentration occurred within the body of the occupied closed-ended shield during a 40-minute period. A slight rise in CO₂ concentration occurred within the immediate vicinity of the infant's head, but at no time did this exceed 0.2%.

Discussion

Preterm and seriously ill babies are routinely nursed in incubators. While such management has undoubtedly contributed to the reduction in the mortality rate of these infants, by providing warmth and reducing heat loss, it is apparent that

the design of some commonly used incubators precludes a stable thermal environment. The majority of incubators presently used are of the forced convection type, incorporating a fan to circulate warm air and a thermostat to regulate the heater unit. Gleiss, in 1956, showed that such on/off heating cycles could cause marked oscillations in environmental air temperature, and Perlstein *et al.* (1970) showed that attacks of apnoea in preterm infants could be triggered by rapid changes in air temperature, particularly during a rise in air temperature, confirming previous observations in newborn animals (Dawes, 1968). A recent study has shown a tendency to a higher mortality rate in infants exposed to higher environmental temperatures in forced convection incubators (Yashiro *et al.*, 1973).

Hey and Mount (1967) have shown that radiant heat loss from an infant can be considerably reduced by enclosing the baby in a perspex heat shield, but measurement of the air temperature inside the shield in relation to the thermal cycle of the incubator was not carried out. Information on air temperature profiles is not readily available from the incubator manufacturers and this compounds the generally uncritical approach of nursing and medical staff to the environmental conditions of the infants under their care.

Our observations show that there are major differences in the air temperature profile between the two types of incubator, which are probably due to differences in the air flow pattern, and differences in the control system of the heating units.

The on/off heating cycle incubator has a predominantly unidirectional air flow, with the thermostat situated in the returning air stream. This means that the incubator air temperature can rise considerably before the returning warm air affects the thermostat. That this does take a long time can be confirmed by observing the duration of illumination of the heating unit indicator light on the control panel, and this explains the cyclical oscillation in air temperature.

In these experiments the temperature controls were preset by the nursing staff, according to routine practice. Under these circumstances it is apparent that significant differences in both the duration of the air temperature cycle and the resulting gradients within the incubator occur between incubators of the same type. Thus in these incubators the roof and above mattress air temperatures could vary by as much as 7.1 and 2.6°C, respectively, though the safety alarm was never triggered. It is our experience that these phenomena are further exaggerated when the incubators

are occupied, as greater temperature oscillations occur as a result of opening the doors.

Fig. 5 shows that significant oscillations in air temperature occur inside the open-ended heat shield. When very low birthweight infants are nursed under these conditions it is possible that a considerable period of time is spent with the immediate air temperature around the infant below the optimum for its age and weight. This is particularly likely to occur when the incubator has a long thermal cycle. On the other hand, the rapid increase in air temperature during the heating phase may also be detrimental in being implicated in the initiation of apnoeic spells. The observation that the infant maintains fairly stable body temperatures during the incubator thermal cycle may be falsely reassuring, and does not reflect the thermal stress suffered by the baby. The oscillation in immediate air temperature around the infant is greatly diminished inside the closed-ended heat shield, thus ensuring a more stable environment. Since there is a predominantly longitudinal air flow in these incubators, we suggest that the open-ended shield acts as a funnel when used inside these machines. Occlusion of the distal end prevents this phenomenon, without causing significant accumulation of CO₂. The glass thermometer mounted in the incubators reflects poorly the thermal environment around the infant inside the heat shields.

In contrast, the air temperatures within the proportional control incubators were uniformly constant, with a narrow gradient. The fine control of the heating unit is achieved by incorporating the proportional control unit in its design which varies the power supplied, and can be shown by observing the constantly flickering heater indicator light on the control panel. Our experience with these incubators has shown that, with minimal opening of the doors, this stable thermal environment persists when the incubators are occupied.

These observations have shown, during routine ward use, important differences in the air temperature profiles of these two commonly used types of incubator. The oscillations in air temperature seen in the model with the on/off heating cycle may provide an environment that is both inadequately warm for part of the cycle, and, as others have reported, may be implicated in the initiation of respiratory difficulties as a result of rapid up-swings in air temperature. These oscillations in air temperature persist in hemicylindrical heat shields, but we suggest that a more stable immediate environment around an infant can be achieved inside such incubators by using a closed-ended shield.

The design of the incubator with proportional heating control appears to offer an important advantage by providing a more stable thermal environment, and in this situation the design of the heat shield may be less critical.

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