

# Simple method for measuring oxygen consumption in babies

O. R. C. SMALES

*From the Department of Child Health, University Hospital and Medical School, Nottingham*

**SUMMARY** A simple open-circuit method for measuring the rate of oxygen consumption in the neonatal nursery is described and preliminary results on 240 infants reported. The findings are consistent with previous studies using closed systems and artificial environments. The variation between one infant and another was great, which makes it difficult to predict for any one infant the thermal environment at which the rate of oxygen consumption will be minimal.

There have been a number of studies showing the importance of keeping sick or preterm infants warm, and many reports describe the thermoregulatory responses of a variety of newborn infants to changes in environmental temperatures. Unfortunately, most of these studies have been made in experimental and therefore artificial environments, although they are still the best guide currently available to the ambient temperatures at which to set incubators or maintain room temperatures in nurseries. However, we still have no method of knowing whether or not the sick or preterm infant in the nursery is feeling comfortably warm, for they may neither sweat appropriately when they are hot, nor shiver when they are cold. Also, as they *can* vary their rate of heat loss by evaporation or their rate of heat production by non-shivering thermogenesis, their body temperatures, which are often used by nursing staff as an index of thermal comfort, will not indicate if the infants are reacting to an inappropriately hot or cold environment.

In order to investigate the thermoregulatory responses of infants in a clinical setting, an open-circuit method was devised that only minimally interfered with the infant and his thermal environment. The technique is here described and some preliminary results given.

## Methods

Air is passed at a known flow rate through a soft, plastic face mask secured over the infant's nose and mouth, and the oxygen content of the outflow measured. The rate of O<sub>2</sub> consumption is the product of the rate of flow and the difference in O<sub>2</sub> concentra-

tion in the inflow and outflow gas. Volumes are corrected to standard temperature and dry pressure.

**The system** (Fig. 1). The paramagnetic O<sub>2</sub> analyser (Servomex OA250) was calibrated with room air and a standard gas mixture (about 18% O<sub>2</sub>) before and after each measurement. Air flow was measured with a flow meter (GEC Elliott 1100 Rotameter) and held at 1 l/min. The air was warmed and humidified by a Vickers Cascade Humidifier after passing through the flow meter.

The accuracy of the method depends on the accuracy of the flow meter, the O<sub>2</sub> analyser, the standard gas mixture, and the absence of leaks. The flow meter was tested by the manufacturers in the range 0.5-1.0 l/min, and its 'probable error' at 760 mmHg atmospheric pressure and 15°C using dry air was  $\pm 3.3\%$ . A correction factor was applied for changes in operating temperature and pressure. Checks against a calibrated spirometer confirmed this accuracy. The O<sub>2</sub> content of the standard gas was certified correct to within 0.1% by the suppliers (British Oxygen Co.), and again this was also confirmed by analysis with a Haldane apparatus. The reproducibility of the O<sub>2</sub> analyser and recorder was tested by repeated determination of the difference in O<sub>2</sub> concentration between room air and the standard gas. On 10 determinations the coefficient of variation was 0.4%.

The integrity of the complete apparatus was tested using known O<sub>2</sub> concentrations. Serial dilutions of air with nitrogen were made with both gases delivered by flow meter to a constant total flow rate of 1 l/min. The theoretical O<sub>2</sub> content was compared with that calculated from the recorded percentage O<sub>2</sub> content of the mixture. The correlation coefficient was 0.99.

Received 15 August 1977

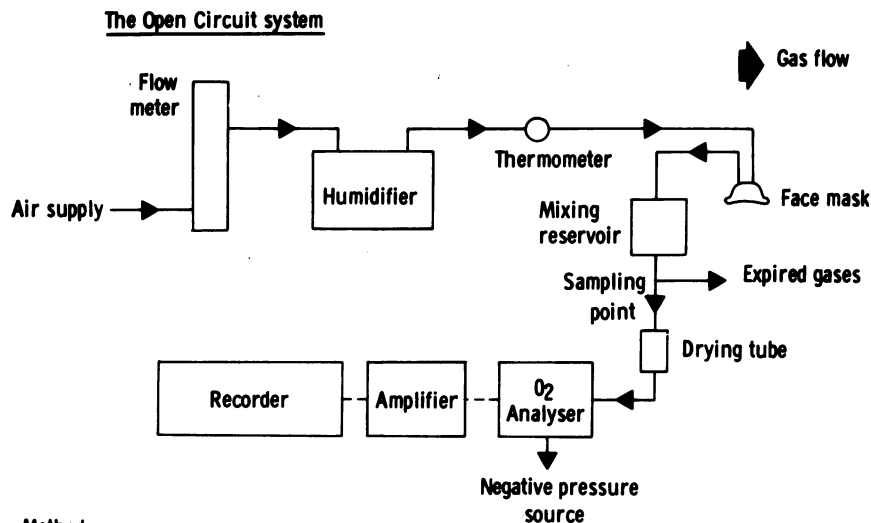


Fig. 1 Measurement of oxygen consumption in the newborn nursery.

### Method

$$V_{O_2} \text{ (STP)} = V_s (F_{iO_2} - F_{sO_2}) \text{ (STP)}$$

$V_{O_2}$  = Rate of oxygen consumption

$V_s$  = Air flow ml/min

$F_{iO_2}$  = Concentration of oxygen in inspired air

$F_{sO_2}$  = Concentration of oxygen in expired air

The method was also assessed by direct comparison with a closed-circuit  $O_2$  consumption apparatus. The  $O_2$  consumption of a 3.02 kg rabbit was first determined by the closed-circuit system. The apparatus was then modified to the open circuit and the measurement repeated. The ambient temperature was within  $0.5^\circ\text{C}$  for each pair of recordings. Five paired results were obtained. The mean variation was 4.2%. During preliminary studies the  $CO_2$  concentration of the mixed expired gas did not exceed 1%, indicating that at a flow rate of 1 l/min no significant rebreathing occurred.

### Patients

In this preliminary investigation, 376 measurements were made in two circumstances. In the first series, 124 measurements were made on 100 infants nursed in cots; disposable nappies were used and the infants wore a nightshirt and were covered by a sheet and cellular blanket. The nursery room air temperatures ranged between 25 and  $29^\circ\text{C}$ . All the infants had been transferred to the Department of Neonatal Medicine because of some problem, commonly low birthweight.

In the second series, 252 measurements were made on 141 infants nursed in incubators (Vickers 59 or

79). These infants were naked apart from nappies. Incubator temperatures were selected by the nursing staff so that the operative environmental temperature should be close to the lower critical temperature according to the values reported by Hey (1971). Servocontrol was not used and the relative humidity was 50–55%. In 95 infants the incubator temperature was deliberately reset, either up or down, and a measurement made at least 20 minutes after the temperature had stabilised. The measurements were made 1 hour after an intermittent feed or during continuous intragastric feeding.  $O_2$  consumption was measured continuously for 20–30 minutes in each instance. The infants were usually asleep, recordings on restless infants being excluded from this report. For the incubator-nursed infants the operative environmental temperature was calculated by subtracting  $1^\circ\text{C}$  from the air temperature recorded in the canopy of the incubator for each  $7^\circ$  difference between incubator and room temperature (Hey and Mount, 1967).

### Results

The rates of  $O_2$  consumption ( $VO_2$ ) of infants in the nursery are shown in Fig. 2. They are consistent with previous published reports and show the well des-

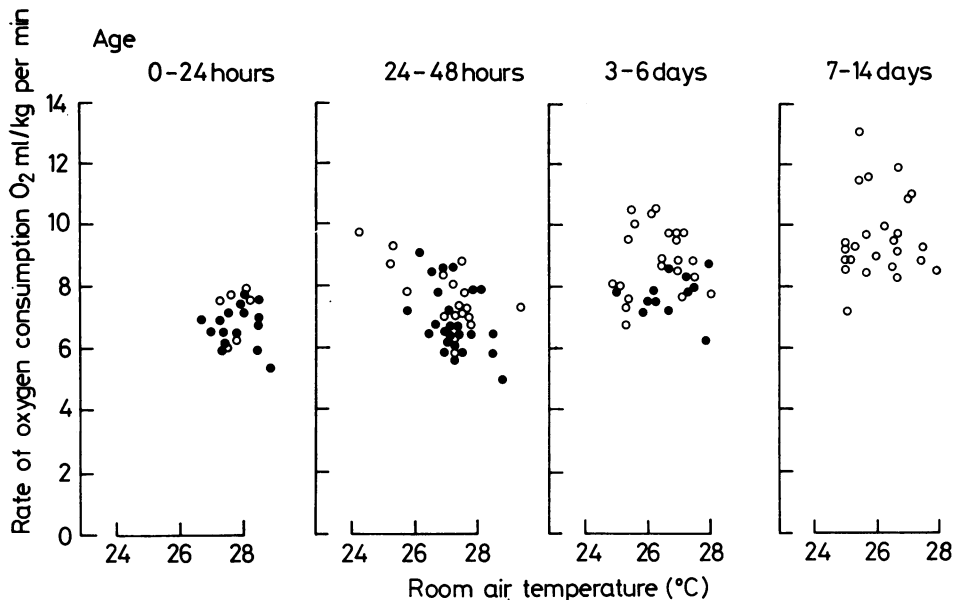


Fig. 2  $O_2$  consumption rate of cot-nursed babies at different room temperatures according to age. ● = babies weighing  $>2.5$  kg; ○ = babies weighing  $<2.5$  kg.

cribed phenomenon of an increase in  $VO_2$  with age; they also show a wide range in rates in infants of similar weight and age nursed at apparently similar ambient temperatures. From single measurements it is not possible to state whether the infant is responding to a cool or a warm environment. There was no apparent difference between infants of different maturity or body weight when the results were expressed per kg body weight.

The rates of  $O_2$  consumption of infants in incubators are shown in Figs. 3 and 4. Again the results are in the range of previously recorded values. The effect of deliberately reducing the incubator temperature did not stimulate as large an increase in  $O_2$  consumption as might have been expected from previous reports, but this may be due to differences in technique. In general, when the incubator temperature was increased,  $O_2$  consumption rate fell, suggesting that the nurses elected to hold the infants in slightly cool environments. The minimal rates of infants in incubators were lower on average than those of similar age and weight nursed in cots. This may be due to the cot-nursed infants having on average a higher minimal rate, or to a relatively cool ambient temperature.

The wide variations in  $O_2$  consumption rates did not appear to be related to colonic temperature in either group, suggesting that body temperatures are not a useful guide in a clinical setting to the infant's

response to environmental temperatures, except at the extremes of the range of thermal control.

### Discussion

A simple open-circuit method has been used to measure rates of  $O_2$  consumption in preterm and term infants nursed in either cots or incubators in a busy department of neonatal medicine. The values are consistent with those found in experimental conditions on both naked (Hey, 1969) and clothed (Hey and O'Connell, 1970) infants. The infants showed the predicted increase in rate with age (Brück, 1961; Hill and Rahimtulla, 1965; Scopes and Ahmed, 1966). However, the increase in rate with lower air temperatures was not as large as was expected from previously reported values (Brück, 1961; Hill and Rahimtulla, 1965; Hey, 1969). This may be due to a number of factors either individually or combined to varying degrees. The calculated operative environmental temperature makes only a crude estimate of those surrounding temperatures which will determine radiant and convective losses, and makes no allowance for conductive losses through the surface on which the baby is lying, thus the calculated operative temperatures will differ in different studies.

Infants in the published experimental observations would be selected to the extent to which it was

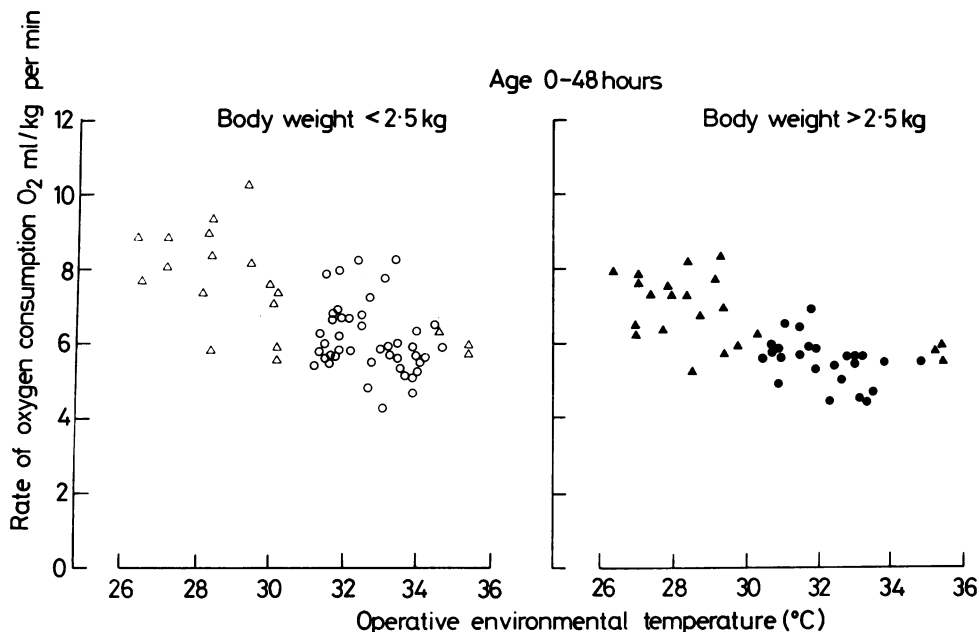


Fig. 3 O<sub>2</sub> consumption rate according to operative environmental temperature in incubator-nursed babies during the first 48 hours of life. Left: babies < 2.5 kg. Right: babies > 2.5 kg. Circles, measurements made at temperatures selected by the nursing staff during routine nursing; triangles, measurements made at least 20 minutes after an alteration of incubator temperature.

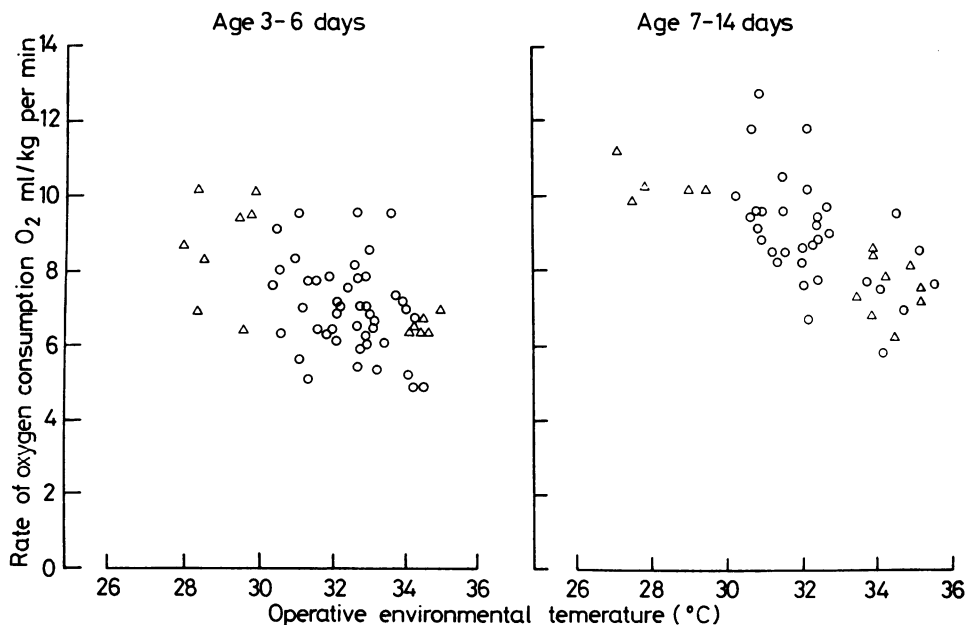


Fig. 4 O<sub>2</sub> consumption rate according to operative environmental temperatures in incubator-nursed babies weighing < 2.5 kg at 3-6 days and 7-14 days of age. ○ = measurements made at temperatures selected by the nursing staff during routine nursing; △ = measurements made at least 20 minutes after an alteration of incubator temperature.

considered safe to take them from their incubator or cot for the period of observation, and thus it is likely that they were selected for their general well-being, and this again will affect their  $O_2$  consumption rates and response to cold environments. In these studies the inspired air temperatures were kept constant and this itself may modify the infant's response to cold, for the upper airways of newborn infants have been shown to be very sensitive to ambient temperature changes (Mestyán *et al.*, 1964; Pribylova, 1971). The variation in responsiveness to cold exposure may also be due to variations in the general well-being of the mother before birth, for in experimental animals this has been shown to influence the response of the newborn (Edson and Hull, 1977), and may also be due to the conditions under which the infants are nursed before the study.

The most striking feature from the clinical management point of view is the wide ranges of metabolic rates in infants that appear very similar with respect to age, weight, gestation, and clinical well-being. The appropriate incubator temperature for an infant with a minimal rate of oxygen consumption of 6 ml  $O_2$ /kg per min is likely to be different from that of an infant producing heat at a rate reflected by an oxygen consumption of 10 ml  $O_2$ /kg per min. The factors determining these variations require investigation for they must be taken into consideration not only in the control of the ambient temperature, but also in calculating the appropriate food requirement. The variation is unlikely to be due to postprandial changes observed by Brooke *et al.* (1973) in older infants, for the measurements were always made one hour after a feed. Fluctuations in rates have been observed during the different sleep states in infants (Stothers and Warner, 1977), but again not to a magnitude to explain the differences seen in this study. Some of the scatter might be reduced if allowances could be made for variations in active cell mass (Bhakoo and Scopes, 1971). The aim of this study was at a more practical level, to discover to what extent averages obtained from experimental observations can be used in a clinical setting to keep rates of  $O_2$  consumption at a minimum.

The results of this simple method for measuring  $O_2$  consumption in the newborn are similar to average published values for groups of infants at various weights and postnatal ages, but there is con-

siderable variation between individual infants. Therefore it is important that the nursing staff continue to be very sensitive to the needs of individual infants for warmth and to be allowed to adjust the ambient conditions appropriately.

#### References

- Bhakoo, O. N., and Scopes, J. W. (1971). Weight minus extra-cellular fluid as metabolic reference standard in newborn baby. *Archives of Disease in Childhood*, **46**, 483-489.
- Brooke, O. G., Harris, M., and Salvoas, C. B. (1973). The response of malnourished babies to cold. *Journal of Physiology*, **233**, 75-91.
- Brück, K. (1961). Temperature regulation in the newborn infant. *Biologia Neonatorum*, **3**, 65-119.
- Edson, J. L., and Hull, D. (1977). The effect of maternal starvation on the metabolic response to cold of the newborn rabbit. *Pediatric Research*, **11**, 793-795.
- Hey, E. N. (1969). The relation between environmental temperature and oxygen consumption in the newborn baby. *Journal of Physiology*, **200**, 589-603.
- Hey, E. N. (1971). The care of babies in incubators. *Recent Advances in Pediatrics*, 4th ed., p. 180. Ed. by D. Gairdner and D. Hull. Churchill, London.
- Hey, E. N., and Mount, L. E. (1967). Heat losses from babies in incubators. *Archives of Disease in Childhood*, **42**, 75-84.
- Hey, E. N., and O'Connell, B. (1970). Oxygen consumption and heat balance in the cot-nursed baby. *Archives of Disease in Childhood*, **45**, 335-343.
- Hill, J. R., and Rahimtulla, K. A. (1965). Heat balance and the metabolic rate of newborn babies in relation to environmental temperature and the effect of age and of weight on basal metabolic rate. *Journal of Physiology*, **180**, 239-265.
- Mestyán, J., Jari, I., Bata, G., and Fakete, M. (1964). Surface temperature versus deep body temperature and the metabolic response to cold of hypothermic premature infants. *Biologia Neonatorum*, **7**, 230-242.
- Pribylova, H. (1971). The effect of temperature of inspired air on the metabolic response of the newborn. *Review of Czechoslovak Medicine*, **17**, 133-136.
- Scopes, J. W., and Ahmed, I. (1966). Minimal rates of oxygen consumption in sick and premature newborn infants. *Archives of Disease in Childhood*, **41**, 407-416.
- Stothers, J. K., and Warner, R. M. (1977). Oxygen consumption and sleep state in the new-born (Abst.). *Journal of Physiology*, **269**, 57P-58P.

I thank Dr A. D. Milner for assistance in developing the method, and Professor D. Hull for advice.

Correspondence to Dr O. R. C. Smales, Department of Child Health, University Hospital and Medical School, Clifton Blvd., Nottingham.