Simple and versatile method for measuring oxygen consumption in infants

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SUMMARY A simple, rapid, and accurate method for measuring oxygen consumption in infants is described. Expired gas is entrained in a stream of air drawn through a gently applied face mask. Oxygen consumption is derived from (1) gas flow rate, measured with a flowmeter, and (2) the fall in oxygen concentration of the gas mixture, measured with a paramagnetic analyser. A measurement can be made at the bedside within 2 minutes without disturbing the infant. In 17 mature 2-day-old neonates mean oxygen consumption was 6.52 ml/kg per min, SD 0.90, similar to that previously reported using less simple methods.

Measurements of oxygen consumption ($\dot{V}O_2$) have been very helpful in physiological studies of the newborn, for example in determining the optimal conditions for a thermoneutral environment in term and preterm infants (Hill and Rahimtulla, 1965; Scopes and Ahmed, 1966; Hill and Robinson, 1968; Bhakoo and Scopes, 1974). They have also proved valuable in the investigation of infants undergoing cardiac catheterisation (Fixler *et al.*, 1974) and cardiac surgery (Owen-Thomas and Meade, 1975), and in the evaluation of the effects of treatment, e.g. postoperative management (Ito *et al.*, 1976) and phototherapy (O. Smales, unpublished, 1976).

Methods previously reported for measuring O_2 consumption usually disturb the infant, are frequently time-consuming, and use relatively complicated and expensive equipment. We describe a simple method for measuring O_2 consumption accurately and quickly with portable apparatus.

Patients and methods

A constant flow system is used and O_2 consumption is derived by the application of the Fick principle. A clear plastic mask with a soft foam-lined rim is gently applied to the face covering the nose and mouth (Figs. 1, 2). The mask is connected to a coaxial circuit through which air is drawn at a constant flow rate. The expired gas from the infant is entrained in the gas stream drawn into the central tube. The gas is dried by silica gel before passing through a flowmeter (Rotameter). Part of the flow

(0.3 l/min) is pumped to a paramagnetic oxygen analyser (Servomex OA272) and allowed to escape to atmosphere; the remainder is drawn to waste through a needle valve and pressure regulator into a

Fig. 1 The apparatus in use.

Received 21 December 1977.

Fig. 2 System for measuring oxygen consumption. Expired gas is entrained in the constant airflow drawn into the mask through the coaxial circuit. The gas flow, after being dried, passes through a flowmeter and is sampled by the pump and paramagnetic oxygen analyser. The analyser reading is displayed on a digital voltmeter (DVM).

piped vacuum system or suction pump. O_2 consumption ($\dot{V}\text{O}_2$) is derived from the sample flow rate ($\dot{V}_s$) and fall in O_2 concentration (FDO_2),

$$\dot{V}\text{O}_2 = \dot{V}_s \times \text{FDO}_2.$$

Appropriate corrections are made for temperature and pressure. No allowance is made for the small volumetric difference between inspired oxygen and expired CO_2 . The oxygen analyser is regularly calibrated with O_2 and N_2O , both of which are readily available (a small correction factor for the difference between N_2 and N_2O is applied). The apparatus is also tested at least weekly for the presence of leaks by drawing pure oxygen through the system.

A sample flow rate of 1.3 l/min per kg is drawn through the mask. This flow rate provides a readily measurable fall in O_2 concentration (approximately 0.5% absolute) but prevents rebreathing of expired gas and loss of expired gas past the soft fitting rim of the face mask (Evans *et al.*, 1977). Because the flowmeter tube is calibrated at atmospheric pressure, it is important that the resistance of the circuit is low so that the pressure within the flowmeter tube is atmospheric. The position of the oxygen analyser is such that it is protected from any changes in circuit pressure caused by changes in sample flow rate, which would otherwise directly affect its calibration. The sensitivity and ease of reading of the analyser is improved by the addition of a digital

voltmeter. A small reservoir is placed between the pump and analyser to smooth out breath-by-breath changes in gas concentration. The volume of the reservoir is adjusted so that a steady reading is obtained within 120 seconds.

A secure airtight seal between the mask and infant is not essential. The high sample flow rate (equal to twice the approximate peak expired flow rate of the neonate) and slight subatmospheric pressure within the mask ensure that expired gas cannot escape from the mask; if a leak is present between the mask and infant, air is drawn into the mask. Since ambient air is drawn through the system additional humidification is not usually necessary; if this is essential, as part of a study of heat balance for instance, this is easily achieved by the insertion of a low resistance humidifier in the inspiratory limb of the system.

If measurements are required of the effects of critical changes in environmental factors, the mask and coaxial circuit may be replaced by a conventional head box or hood.

Laboratory verification. In order to check the accuracy and linearity of response of the system, O_2 consumption was simulated by the injection of a steady flow of N_2 into the central tube of the coaxial circuit. N_2 entered the circuit at a range of flows from approximately 50 to 250 ml/min. The true flow rate was derived using a wet-gas meter (Parkinson and Cowan Type B) and stop-watch. Appropriate corrections were applied for temperature pressure and humidity.

Clinical measurements. O_2 consumption was measured in 17 healthy, term 2-day-old babies, while they were sleeping clothed in their cots 2–3 hours after feeds. The studies were made in an environment of moderate humidity which was carefully maintained within the neutral temperature range for each baby, meeting Hey's (1971) criteria for thermal neutrality.

Results

Laboratory verification. The correlation between measured and simulated $\dot{V}\text{O}_2$ is shown in Fig. 3. The 95% confidence limits of the measured values are virtually constant at approximately ± 1.5 ml/min over the range 10–50 ml/min.

Clinical measurements. The mean $\dot{V}\text{O}_2$ was 6.52 ml STPD/kg per min, SD 0.90. These values accord with figures obtained by other workers using both closed and open-circuit techniques (see Table). The infants' ages ranged from 32 to 60 hours, mean 48 hours; their mean weight was 3.12 kg, SD 0.5.

Fig. 3 Correlation (unconstrained regression line with 95% confidence limits of a single observation) of measured $\dot{V}O_2$ and simulated $\dot{V}O_2$. Equation: $y=0.991x + 0.19$; $r=0.9991$.

Table Comparative values of $\dot{V}O_2$ in neonates

Published reports	Age (h)	No. of babies	$\dot{V}O_2$ (ml/kg per min) (mean $\pm$ SD)
Present method	32-60	17	6.52 ± 0.90
Hill and Rahimtulla (1965)	48-96	16	6.70 ± 0.70
Hill and Robinson (1968)	33-47	11	6.44 ± 1.21
Scopes and Ahmed (1966)	1w	39	5.96 ± 0.77

Discussion

Other methods (Hill and Rahimtulla, 1965; Hill and Robinson, 1968; Scopes and Ahmed, 1966; Stoker *et al.*, 1973; Fixler *et al.*, 1974; Smales, 1978) involve placing the infant in a sealed box or collecting expired air from a hood or tightly applied mask to avoid leakages. The high fresh gas flow used in our method not only ensures that expired gas does not escape past leaks at the rim of the mask (Evans *et al.*, 1977) but also ensures that rebreathing of expired gas does not occur. At gas flows of less than twice the minute volume, rebreathing is likely to occur (Willis *et al.*, 1975). Assuming, in the neonate, a minute volume of 300 ml/kg per min the fresh gas flow should therefore exceed 600 ml/kg per min. The use of lower fresh gas flows (500 to 1000 ml/min; Smales, 1978) will almost certainly result in CO_2

retention in all but the smallest neonates; this cannot be excluded by measurements of CO_2 concentration in mixed expired gas obtained from a T-piece arrangement. The Servomex OA272 analyser used in the present system is ideal for this type of investigation and obviates the need for additional amplification, recording, and calibration equipment.

The present method can be quickly and repeatedly performed from within minutes of birth and produces accurate results without disturbing the infant. The equipment is relatively simple, inexpensive, and portable. The measurement of O_2 consumption by this method has many potential applications in special-care nurseries and paediatric wards. We have used it to make several hundred measurements of O_2 consumption in neonates and infants in the labour wards, special care nursery, and in the follow-up of older infants as outpatients.

We gratefully acknowledge the assistance of Sister I. Wardrop, of the Nursing Staff of the Maternity Department, University Hospital of Wales, and of Mrs Jeanette Brown, who typed the manuscript.

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