0031-3998/86/2007-0646$02.00/0
PEDIATRIC RESEARCH
Copyright © 1986 International Pediatric Research Foundation, Inc.

Vol. 20, No. 7, 1986
Printed in U.S.A.

Estimation of 24-Hour Energy Expenditure from Shorter Measurement Periods in Premature Infants

EDWARD F. BELL, GLADYS R. RIOS, AND PATRICIA K. WILMOTH

Department of Pediatrics, University of Iowa, Iowa City, Iowa 52242

ABSTRACT. We performed continuous indirect calorimetry for 24 h on nine occasions in small premature infants. Oxygen consumption, carbon dioxide production, respiratory quotient, and energy expenditure were calculated for each 2-h period. The mean energy expenditure during the first 6 h was within 6.5% of the mean for the whole 24-h period in all but one case. The mean error in estimating total daily energy expenditure from 6-h measurements was 0.9%. Because positive and negative errors tend to offset each other, we also calculated the mean absolute error, which was 5.6%. The mean coefficient of variation in energy expenditure among the 2-h periods was 11.0%. The mean coefficients of variation in oxygen consumption, carbon dioxide production, and respiratory quotient were 12.8, 9.9, and 14.1%, respectively. Total daily energy expenditure of small premature infants can be estimated from measurements as short as 6 h with sufficient accuracy for most purposes. (*Pediatr Res* 20: 646–649, 1986)

Abbreviations

$\dot{V}O_2$, oxygen consumption
$\dot{V}CO_2$, carbon dioxide production
RQ, respiratory quotient

In order to learn more about growth of infants, it is important to understand how dietary energy is utilized. Ingested energy that is not excreted in the feces or urine is either expended for metabolism or stored in body tissues (1, 2). By measuring energy intake, excretion, and expenditure it is possible to calculate the energy stored in the body during growth. Relating the energy stored to the rate of weight gain provides insight into the composition of new tissues during growth; fat contains a higher concentration of energy than nonfat tissues.

Energy intake and excretion can be determined by collecting and analyzing aliquots of diet and excreta during balance studies of at least several days. Energy expenditure, however, is considerably more difficult to measure, and few attempts have been made to measure energy expenditure of infants for periods of 24 h or longer (3–6). More frequently, 24-h energy expenditure has been estimated from indirect calorimetry of shorter duration, usually periods of 6 h or less (7–13).

In adults, 24-h energy expenditure cannot be accurately predicted from brief measurement periods due to the influences of activity, sleep, and meals on energy expenditure (14, 15). Moreover, it is not possible to perform calorimetric studies of adult subjects during their normal range of activities (14). On the other hand, premature newborn infants are fed frequently at regular intervals, sleep much of the time, and are relatively inactive when awake.

For these reasons it is possible, although difficult, to perform continuous indirect calorimetry of premature infants for whole 24-h periods. For the same reasons, we postulated that the premature infant's energy expenditure might be more uniform over time and, therefore, more accurately predictable from shorter periods of measurement. This study was undertaken to determine how accurately total daily energy expenditure of premature infants can be estimated from measurement periods of less than 24 h.

METHODS

Nine 24-h measurements of energy expenditure were performed on five premature infants, four male and one female. Their demographic data are summarized in Table 1. Four infants were studied twice. The first study was at the age of 4 to 13 days, when the infants required no ventilatory support or supplemental oxygen and were receiving a combination of intravenous and enteral nutrition (mean water intake 66% enteral); three of four infants weighed less than at birth. The second study was 3 wk later when all infants were tolerating fully enteral feedings and steadily gaining weight. The fifth infant was studied only once, at age 24 days, while feeding and growing well. All infants were fed premature formula by gavage every 3 h. The feeding tube was left in place, and energy expenditure measurements were not interrupted during feeding. The formula composition and volume per feeding were constant throughout the 24-h study periods. Gross energy intake ranged from 76 to 122 kcal/kg per day (mean 101). All studies began in the morning between 0900 and 1200.

The infants were nursed naked in a single-walled incubator (Air-Shields C-100 Isolette), which was operated according to the usual nursing routine. During four studies (nos. 1, 3, 5, and 8 in Table 1) the incubator was operated in the skin temperature servocontrol mode (control temperature 36.0 to 36.4° C); during the other five studies (nos. 2, 4, 6, 7, 9) the air temperature control mode was used (control temperature 31.5 to 34.0° C). We have previously shown (16) that the energy expenditure of premature infants is not systematically influenced by the mode of incubator control. Axillary temperature was measured every 2 to 4 h and the control temperature adjusted if the axillary temperature was not within the desired range of 36.5 to 37.4° C [mean ± 1.5 SD for normal term infants (17)]. Routine nursing and medical care were continued without interruption.

Energy expenditure was determined by continuous indirect calorimetry as previously described (18). $\dot{V}O_2$ and $\dot{V}CO_2$ were

---

Received November 26, 1985; accepted March 4, 1986.

Correspondence and reprint requests to Edward F. Bell, M.D., Department of Pediatrics, University of Iowa, Iowa City, IA 52242.

This work was supported by grants from the National Institutes of Health (HD16974, HD07578, RR00059) and the March of Dimes Birth Defects Foundation (6-356), and by a grant-in-aid from Gerber Products Company.

measured with a ventilated-hood, open circuit system. Exhaled air was completely entrained in room air withdrawn from a head hood made of acrylic and polyethylene. The system flow rate was controlled at 3 liter/min per kg body weight with an electronic flow controller and flowmeter (Matheson 8240-0414). Oxygen and carbon dioxide concentrations were constantly recorded and compared periodically with ambient (inspired) air. A paramagnetic oxygen analyzer (Servomex 0A540) and an infrared carbon dioxide analyzer (Beckman LB2) were used. The analyzers were attached to integrating chart recorders and, in the most recent studies, to an electronic data logging system.

The oxygen and carbon dioxide analyzers were calibrated with pure nitrogen and a gas mixture of known composition that had been analyzed by the Haldane procedure (19, 20). The flowmeter was calibrated by the timed filling of a 120-liter spirometer. The whole system has been validated by calculating the simulated gas exchange resulting from the addition of pure nitrogen (21) or carbon dioxide at known rates. The error of the system under these conditions is less than 5%.

The mean concentrations of oxygen and carbon dioxide in the sample and ambient gases and the flow rate of gas through the system were used to calculate the mean $\dot{V}O_2$, $\dot{V}CO_2$, and RQ for each 30-min period, correcting for the difference between inspired and expired volumes when the RQ is not 1.0 (18, 22). These values were corrected to standard temperature and pressure.

Energy expenditure was calculated for each 30-min period from the mean $\dot{V}O_2$ and $\dot{V}CO_2$, using the equations of Lusk (23) but assuming that protein oxidation was negligible. The error produced by this assumption is less than 1% (see footnote 34 in Reference 18). Mean $\dot{V}O_2$, $\dot{V}CO_2$, RQ, and energy expenditure were available for each 30-min period except for the times when the system was being recalibrated. Recalibration was performed every 4 to 6 h and required about 40 min. Data were also lost for shorter periods when the head hood was removed for weighing the infant (once in 24 h), replacing the feeding tube (only when inadvertently dislodged), or performing x-ray studies. The mean total duration of data lost during 24 h was 3.9 h.

Mean $\dot{V}O_2$, $\dot{V}CO_2$, RQ, and energy expenditure were then calculated for each 2-h period. The entire 2-h period was omitted if more than 30 min of data were missing because of recalibration or hood removal. In one study, the entire last 8 h of data were lost because of a calibration error. The coefficient of variation among these 2-h periods was calculated for $\dot{V}O_2$, $\dot{V}CO_2$, RQ, and energy expenditure. Successive 2-h periods were combined, beginning with the first (*e.g.* 0–2, 0–4, 0–6, . . . h), to assess how closely $\dot{V}O_2$, $\dot{V}CO_2$, RQ, and energy expenditure measurements over these shorter durations would approximate mean gas exchange and energy expenditure over the entire 24-h period. In this analysis, we assumed that data from missing periods would have been the same as the cumulative mean from all previous periods. The percent error and absolute error (disregarding sign) were calculated by comparing the mean values for $\dot{V}O_2$, $\dot{V}CO_2$, RQ, and energy expenditure over these shorter periods to the 24-h means.

This method allowed measurement of energy expenditure over long periods during the full range of nursing and medical interventions under normal nursery conditions.

The protocol was approved by the Human Subjects Review Committee of the University of Iowa. Informed consent was obtained from the parents of each subject.

Table 1. *Demographic data*

Subject	Birth wt (kg)	Gestational age (wk)	Study	Wt (kg)	Age (day)	Energy intake ($kcal\cdot kg^{-1}\cdot day^{-1}$)
1	1.39	32	1	1.31	11	88
			2	1.62	31	105
2	1.02	28	3	1.11	13	103
			4	1.68	34	122
3	1.26	30	5	1.19	10	81
			6	1.68	31	110
4	1.18	30	7	1.81	24	114
5	1.43	33	8	1.36	4	76
			9	1.86	23	106
Mean	1.26	30.6		1.51	20.1	101

RESULTS

Table 2 shows the variability in energy expenditure among the 2-h periods for each study. The coefficient of variation ranged from 6.7 to 17.0% with a mean of 11.0%.

The total energy expenditure over the entire 24-h period ranged from 46.2 to 72.3 kcal/kg with a mean of 59.8 kcal/kg (Table 3). The mean error in estimating 24-h energy expenditure from a 2-h measurement period (difference between 2- and 24-h means) was −2.8%; the mean absolute error was 8.6%. With 6 h of measurement the mean error was reduced to 0.9%, with a mean absolute error of 5.6%.

Table 4 shows the errors in estimating 24-h $\dot{V}O_2$, $\dot{V}CO_2$, and RQ from shorter measurements. With 6 h the mean errors for $\dot{V}O_2$, $\dot{V}CO_2$, and RQ were 0.5, 3.1, and 2.8%, respectively; the mean absolute errors were 7.3, 6.2, and 11.0%, respectively.

DISCUSSION

Our results indicate that total daily energy expenditure of small premature infants can be estimated with reasonable accuracy from indirect calorimetry over periods as brief as 6 h. The mean error in estimating 24-h energy expenditure from 6-h measurements was 0.9%, and the mean absolute error as 5.6%. Moreover,

Table 2. *Energy expenditure ($kcal\cdot kg^{-1}\cdot day^{-1}$) during 12 consecutive 2-h periods*

Study	Time (h) 0–2	2–4	4–6	6–8	8–10	10–12	12–14	14–16	16–18	18–20	20–22	22–24	Coefficient of variation (%)
1	55.2	53.0	58.2	50.4	57.3	58.7	58.8	58.5	66.8	56.6	56.9	57.0	6.7
2	57.3	65.9	62.5	61.2	63.1	61.5	76.1	69.2	67.3	56.8	57.9	62.6	8.7
3	62.1	76.4	65.3		61.7	62.2	54.4	58.2	68.0		68.5	64.5	9.4
4	72.2	85.9	68.3	66.1	78.9	71.6	66.7	72.6	75.6	69.7	63.0	73.7	8.7
5	50.0	48.3	56.4	58.9	55.6	46.9	49.6	34.6	42.1	37.4	51.0	62.4	17.0
6	62.1	59.0	50.5	50.3	50.0	47.3	39.2	44.2	44.5	54.0	58.7	45.6	13.8
7	37.9	51.7	44.1	36.1	46.1	45.5	51.9	56.2					15.1
8	67.2	68.2	66.6		67.9	77.3	74.4	67.6	65.5	81.2	70.5	71.4	7.1
9	57.3	67.1	57.2	48.6	79.2	66.4	61.3	65.1	72.3	68.9	68.4	62.5	12.3
Mean													11.0

Table 3. *Error in estimating 24-h energy expenditure from shorter periods*

Study	Time (h) 0–2	0–4	0–6	0–8	0–10	0–12	0–14	0–16	0–18	0–20	0–22	0–24
1	55.2*	54.3	55.5	54.0	54.7	55.0	55.6	56.0	57.4	57.3	57.3	57.3
2	57.3	61.0	61.4	61.4	61.8	61.7	64.1	64.8	65.1	64.4	63.7	63.6
3	62.1	69.2	67.9	67.9	66.7	65.9	64.8	63.7	64.2	64.2	64.7	64.5
4	72.2	79.1	76.1	73.5	74.6	74.2	73.3	73.2	73.5	73.2	72.1	72.3
5	50.0	49.1	51.6	52.6	53.3	52.3	51.9	50.1	49.1	47.8	48.0	49.6
6	62.1	61.1	56.9	55.8	54.3	52.9	50.6	49.7	49.1	49.5	50.0	49.6
7	37.9	44.8	44.5	42.4	42.8	43.3	44.6	46.2	46.2	46.2	46.2	46.2
8	67.2	67.6	67.2	67.2	67.4	69.5	70.4	69.9	69.4	70.1	70.1	70.3
9	57.3	62.2	60.8	58.2	62.9	63.5	63.2	63.3	64.4	64.9	65.3	65.0
Mean	57.9	60.9	60.2	59.2	59.8	59.8	59.8	59.7	59.8	59.7	59.7	59.8
(SD)	(10.0)	(10.5)	(9.5)	(9.4)	(9.5)	(9.7)	(9.7)	(9.5)	(9.8)	(10.0)	(9.7)	(9.5)
Mean error† (%)	−2.8	2.1	0.9	−0.7	0.2	0.0	0.1	−0.2	−0.1	−0.2	−0.2	
(SD)	(12.1)	(9.6)	(6.8)	(7.6)	(5.9)	(4.3)	(2.7)	(1.6)	(1.3)	(1.5)	(1.2)	
Mean absolute error (%)	8.6	6.8	5.6	6.4	5.0	3.6	2.1	1.2	1.0	0.8	0.6	
(SD)	(8.5)	(6.6)	(3.6)	(3.4)	(2.4)	(1.9)	(1.5)	(0.9)	(0.7)	(1.2)	(1.1)	

* Energy expenditure in $kcal \cdot kg^{-1} \cdot day^{-1}$.

† Error compared with 0–24 h mean.

Table 4. *Errors in estimating 24-h $\dot{V}O_2$, $\dot{V}CO_2$, and RQ from shorter periods*

	Time (h) 0–2	0–4	0–6	0–8	0–10	0–12	0–14	0–16	0–18	0–20	0–22	0–24	Coefficient of variation among 2-h periods (%)
$\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$)													
Mean	8.14	8.63	8.59	8.44	8.54	8.55	8.56	8.54	8.57	8.56	8.56	8.58	12.8
(SD)	(1.60)	(1.66)	(1.44)	(1.45)	(1.40)	(1.40)	(1.39)	(1.38)	(1.43)	(1.44)	(1.40)	(1.37)	(4.7)
Mean error (%)	−4.7	0.8	0.5	−1.3	−0.3	−0.4	−0.2	−0.5	−0.1	−0.3	−0.2		
(SD)	(16.4)	(13.6)	(9.7)	(10.2)	(7.4)	(5.6)	(3.3)	(2.0)	(1.6)	(1.8)	(1.6)		
Mean absolute error (%)	12.3	10.3	7.3	8.0	6.2	4.6	2.6	1.5	1.2	1.0	0.8		
(SD)	(11.2)	(8.2)	(5.9)	(5.7)	(3.5)	(2.8)	(1.8)	(1.3)	(0.9)	(1.4)	(1.4)		
$\dot{V}CO_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$)													
Mean	7.43	7.63	7.34	7.24	7.27	7.26	7.22	7.19	7.16	7.15	7.16	7.14	9.9
(SD)	(1.37)	(1.31)	(1.30)	(1.25)	(1.28)	(1.32)	(1.31)	(1.31)	(1.27)	(1.31)	(1.32)	(1.33)	(2.7)
Mean error (%)	4.5	7.3	3.1	1.8	2.2	1.6	1.2	0.8	0.3	0.1	0.2		
(SD)	(10.8)	(7.6)	(7.5)	(7.0)	(5.9)	(3.8)	(3.4)	(1.6)	(1.4)	(0.9)	(0.5)		
Mean absolute error (%)	8.9	8.8	6.2	4.8	4.6	3.2	2.4	1.2	1.2	0.7	0.3		
(SD)	(7.0)	(5.6)	(4.8)	(5.2)	(4.1)	(2.5)	(2.6)	(1.3)	(0.6)	(0.4)	(0.4)		
RQ													
Mean	0.94	0.91	0.87	0.88	0.87	0.86	0.86	0.86	0.86	0.86	0.85	0.85	14.1
(SD)	(0.20)	(0.16)	(0.13)	(0.14)	(0.12)	(0.10)	(0.10)	(0.10)	(0.10)	(0.09)	(0.10)	(0.10)	(6.2)
Mean error (%)	10.5	7.2	2.8	3.6	2.6	1.9	1.4	1.2	0.5	0.5	0.5		
(SD)	(21.5)	(18.3)	(14.4)	(14.0)	(9.8)	(7.5)	(4.7)	(2.8)	(2.1)	(2.0)	(1.3)		
Mean absolute error (%)	19.7	15.9	11.0	11.0	7.7	5.4	3.2	1.9	1.7	1.6	0.8		
(SD)	(12.4)	(10.5)	(8.9)	(8.5)	(6.1)	(5.4)	(3.6)	(2.3)	(1.2)	(1.1)	(1.1)		

the error exceeded 6.5% in only one of nine studies. With 12 h of measurement, the error was always less than 7%; in fact the mean error was −0.03% and the mean absolute error 3.6%.

Thus a 6-h period of measurement seems to be sufficient for most investigative purposes, although additional accuracy can be gained by extending the measurements to 12 h. Little further is gained by prolonging the measurements beyond 12 h.

A 6-h measurement period is also recommended because it includes two full interfeeding epochs. Shorter periods might systematically exclude part of the energy expenditure associated with feeding. When the interval between feedings is 2 h, a 6-h measurement period would include three complete interfeeding epochs. If feedings are 4 h apart, energy expenditure should be measured for 8 h, to include two full interfeeding epochs.

Our analysis was not designed to assess the effect of feeding on energy expenditure nor the contribution of feeding to the variability in energy expenditure. Because we chose 2-h periods for analysis in infants who were fed every 3 h, eight of twelve 2-h periods included feedings, whereas four did not. One would anticipate similar or even lower variability in energy expenditure had we analyzed by 3-h segments, as other investigators have done (5, 6).

Gudinchet *et al.* (4) measured $\dot{V}O_2$ every 5 min for 24 h in three infants; the coefficients of variation were 3.5 to 6.6%. They concluded that measurements as brief as 1.5 h would be adequate to predict 24-h $\dot{V}O_2$. However, our data support the recommendation of Abdulrazzaq and Brooke (5) that measurements should be made over at least 6 h.

REFERENCES

1. Brody S 1945 Bioenergetics and Growth with Special Reference to the Efficiency Complex in Domestic Animals. Reinhold Publishing Corporation, New York
2. Sinclair JC 1978 Energy balance of the newborn. In: Sinclair JC (ed) Temperature Regulation and Energy Metabolism in the Newborn. Grune & Stratton, New York, pp 187–204
3. Levine SZ, McEachern TH, Wheatley MA, Marples E, Kelly MD 1935 Respiratory metabolism in infancy and in childhood. XV. Daily energy requirements of normal infants. Am J Dis Child 50:596–620
4. Gudinchet F, Schutz Y, Micheli JL, Stettler E, Jéquier E 1982 Metabolic cost of growth in very low-birth-weight infants. Pediatr Res 16:1025–1030
5. Abdulrazzaq YM, Brooke OG 1984 Respiratory metabolism in preterm infants: the measurement of oxygen consumption during prolonged periods. Pediatr Res 18:928–931
6. Schulze K, Stefanski M, Masterson J, Kashyap S, Sanocka U, Forsyth M, Ramakrishnan R, Dell R 1986 An analysis of the variability in estimates of bioenergetic variables in preterm infants. Pediatr Res 20:422–427
7. Gordon HH, Levine SZ, Deamer WC, McNamara H 1940 Respiratory metabolism in infancy and in childhood. XXIII. Daily energy requirements of premature infants. Am J Dis Child 59:1185–1202
8. Brooke OG, Alvear J, Arnold M 1979 Energy retention, energy expenditure, and growth in healthy immature infants. Pediatr Res 13:215–220
9. Reichman B, Chessex P, Putet G, Verellen G, Smith JM, Heim T, Swyer PR 1981 Diet, fat accretion, and growth in premature infants. N Engl J Med 305:1495–1500
10. Whyte RK, Haslam R, Vlainic C, Shannon S, Samulski K, Campbell D, Bayley HS, Sinclair JC 1983 Energy balance and nitrogen balance in growing low birthweight infants fed human milk or formula. Pediatr Res 17:891–898
11. Sauer PJJ, Dane HJ, Visser HKA 1984 Longitudinal studies on metabolic rate, heat loss, and energy cost of growth in low birth weight infants. Pediatr Res 18:254–259
12. Putet G, Senterre J, Rigo J, Salle B 1984 Nutrient balance, energy utilization, and composition of weight gain in very-low-birth-weight infants fed pooled human milk or a preterm formula. J Pediatr 105:79–85
13. Catzeflis C, Schutz Y, Micheli JL, Welsch C, Arnaud MJ, Jéquier E 1985 Whole body protein synthesis and energy expenditure in very low birth weight infants. Pediatr Res 19:679–687
14. Durnin JVGA, Passmore R 1967 Energy, Work and Leisure. Heinemann Educational Books Ltd, London
15. Webb P 1981 Energy expenditure and fat-free mass in men and women. Am J Clin Nutr 34:1816–1826
16. Bell EF, Rios GR 1983 Air versus skin temperature servocontrol of infant incubators. J Pediatr 103:954–959
17. Mayfield SR, Bhatia J, Nakamura KT, Rios GR, Bell EF 1984 Temperature measurement in term and preterm neonates. J Pediatr 104:271–275
18. Bell EF, Rios GR 1983 A double-walled incubator alters the partition of body heat loss of premature infants. Pediatr Res 17:135–140
19. Haldane J 1892 A new form of apparatus for measuring the respiratory exchange of animals. J Physiol (Lond) 13:419–430
20. Consolazio CF, Johnson RE, Pecora LJ 1963 Physiological Measurements of Metabolic Functions in Man. McGraw-Hill, New York, pp 61–71
21. Kappagoda CT, Linden RJ 1972 A critical assessment of an open circuit technique for measuring oxygen consumption. Cardiovasc Res 6:589–597
22. Lister G, Hoffman JIE, Rudolph AM 1974 Oxygen uptake in infants and children: a simple method for measurement. Pediatrics 53:656–662
23. Lusk G 1928 The Elements of the Science of Nutrition, 4th ed. WB Saunders Co, Philadelphia, pp 61–74