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Heart Rates of Breast-Fed and Formula-Fed Infants

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Summary: Heart rates of 46 breast-fed and formula-fed infants were monitored continuously for ~18 h at 1 or 4 months of age. Heart rate differed significantly by age (1 month > 4 months; $p < 0.001$) and feeding mode (breast-fed < formula-fed; $p < 0.001$). Approximately 58% of the variability in heart rate could be attributed to feeding mode, sex, and age. Heart rate was correlated significantly with energy intake ($r = 0.60$; $p < 0.001$), but not sleeping metabolic rate or total daily energy expenditure. Energy intake accounted for none of the variability in heart rate beyond that explained by feeding mode, sex, and age. **Key Words:** Heart rate—Breast-feeding—Formula-feeding.

Although the effects of maturation, food intake, and muscular activity on infant heart rates are well documented (1,2), the influence of feeding mode has not been examined, except for short periods during sleep in the early neonatal period (3). We have observed lower rates of energy intake and energy expenditure among breast-fed compared with formula-fed infants at 1 and 4 months of age (4,5). We report mean 18-h heart rates in a subset of infants enrolled in our previous studies and examine the interrelationships between heart rate, energy intake, energy expenditure, and feeding mode.

MATERIALS AND METHODS

Subjects

Heart rate measurements were available on 46 of the 105 infants enrolled into either of two studies (4,5). Heart rate data were available on a subset of infants only because the heart rate monitor was purchased midway through the first study; data were incomplete on other infants due to poor electrode placement. All infants by design were the result of term delivery, appropriate size for gestational age, and above the 10th National Center for Health Statistics weight-for-age percentile at birth. At the time of study, infants were 1 or 4 months of age and were healthy. Infants had been fed primarily human milk or formula exclusively since birth (>90% of mean daily intake). The formulas used were Enfamil (Mead Johnson and Company, Evansville, IN, U.S.A.) and Similac (Ross Laboratories, Columbus, OH, U.S.A.) with and without supplemental iron. A description of the infants is given in Table 1.

Study Design

Infants were admitted to the Clinical Research Center at Texas Children's Hospital at 10:00 a.m. for approximately 24 h. Continuous heart rate monitoring commenced at ~4:00 p.m. and was terminated at 10:00 a.m. In addition to heart rate monitoring, infants underwent the following procedures, the results of which have been published (4,5): routine physical examination, anthropometry, assessment of food intake, and measurement of energy expenditure. Food intake was assessed for 3–5 days at home by the test-weighing procedure and by pre- and postweighing of formula and supplemental food bottles. Energy expenditure was measured by indirect calorimetry for 3–4 h postprandially while the infants slept. The sleeping metabolic rate (SMR)

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TABLE 1. *Description of the infants*

	Breast-fed infants		Formula-fed infants	
	1 mo	4 mo	1 mo	4 mo
Sample size (n)	11	11	12	12
Sex (M/F)	8/3	6/5	7/5	4/8
Body weight (kg)	4.77 (0.64)	6.73 (0.72)	4.74 (0.48)	6.71 (0.52)
Length (cm)	55.4 (2.0)	62.5 (2.1)	55.2 (2.1)	62.5 (1.5)
Sum of skinfolds (mm)[a]	36.2 (5.8)	42.1 (9.0)	35.4 (4.5)	45.3 (9.7)
BMI (kg/m^2)	15.4 (1.2)	17.2 (1.5)	15.5 (1.0)	17.2 (1.3)
Energy intake (kcal/kg/day)	103 (17)	74 (8)	114 (14)	97 (12)
SMR (kcal/kg/day)	49.0 (3.7)	46.8 (4.7)	50.7 (4.1)	50.8 (4.0)
MOEE (kcal/kg/day)	43.3 (4.1)	42.6 (5.1)	45.4 (3.5)	45.6 (3.8)

Values are mean (±SD).
[a] Triceps, biceps, subscapular, quadriceps, and flank.

was defined as either the mean energy expenditure 2–3 or 3–4 h from the end of feeding. Minimal observable energy expenditure (MOEE) was defined as the lowest rate of energy expenditure sustained for at least 5 min during the measurement of SMR. Total daily energy expenditure (TDEE) was measured by the doubly labeled water method in the second study only (5); heart rate and TDEE data were available on 27 infants.

Heart Rate Monitoring

The Depex heart rate monitor was used (Depex B.V., Dorpsstraat, The Netherlands) (6). This system consists of two electrodes, a heartbeat integrator (HRM-4k), and a read-out unit (HRMO). The electrodes were attached over the manubrium sternum and the fifth to seventh intercostal space at the anterior axillary line on the left side of the body. The integrator box (24 × 63 × 115 mm, 245 g), once connected to the infant, was placed in the crib or carried by the caretaker. Each R-R interval was detected, analyzed, recorded, and stored at 1-min intervals in one of the 13 registers of the integrator corresponding to 13 preprogrammed heart rate ranges. Data were retrieved by the read-out unit and sent to a storage device, in this case a Sperry computer.

The study was approved by the Institutional Human Experimentation Committees of Baylor College of Medicine and Texas Children's Hospital. Written, informed parental consent was obtained for all studies.

Statistical Analysis

Analysis of variance (SPSS-X) (7) was used to determine the effect of feeding mode (human milk or formula), sex, and age (1 month or 4 months) on heart rate. The percentage of total beats for each heart rate interval and the overall mean heart rate were calculated for each infant, after which the group means (SD) were computed. Regression analysis (Minitab) (8) was used to relate energy intake and expenditure to heart rate.

RESULTS

Heart rate distribution of the breast-fed and formula-fed infants at 1 and 4 months of age is summarized in Table 2 and in Figures 1 and 2. Monitoring time averaged mean (±SD) 1,100(233) min and did not differ by feeding mode, sex, or age. The overall mean heart rate differed by feeding mode (breast-fed < formula-fed; $p < 0.001$) and age (1 month > 4 months; $p < 0.001$). The patterns of heart rate distribution of the breast-fed and formula-fed infants were similar with respect to dispersion (F-test), but differed in central location. A significant interaction was encountered between sex and age ($p < 0.04$). Heart rates averaged 149(±8) and 149(±7) bpm at 1 month ($p < 0.76$), and 128(±5) and 138(±10) bpm at 4 months ($p < 0.02$) for boys and girls, respectively.

With or without adjustment for age, heart rate was significantly correlated with energy intake (kcal/kg/day; $r = 0.60$, $p < 0.001$); with adjustment for age, sex, and feeding mode, energy intake was no longer significant. Heart rate was not significantly related to SMR ($r = 0.25$, $p < 0.09$), MOEE ($r = 0.13$, $p < 0.39$), or TDEE ($r = 0.04$, $p < 0.82$) (kcal/kg/day). Because of the decrease in heart rate associated with age, heart rate was inversely correlated with TDEE (kcal/day; $n = 27$, $r = -0.62$, $p < 0.001$). When adjusted for age or weight, heart rate was not significantly correlated with TDEE (kcal/

TABLE 2. *Heart rate distribution of breast-fed and formula-fed infants at 1 and 4 months of age*

Heart rate interval (bpm)	% Total beats			
	Breast-fed infants		Formula-fed infants	
	1 mo	4 mo	1 mo	4 mo
50–69	0.04 (0.07)	0.04 (0.08)	0.06 (0.07)	0.06 (0.08)
70–89	0.26 (0.58)	0.04 (0.05)	0.05 (0.07)	0.15 (0.22)
90–99	0.28 (0.49)	0.46 (0.51)	0.11 (0.31)	0.38 (0.65)
100–109	0.42 (0.90)	11.80 (10.10)	0.24 (0.74)	1.18 (1.84)
110–119	1.32 (1.73)	24.10 (10.90)	0.89 (1.69)	8.90 (14.0)
120–129	9.00 (7.70)	21.20 (9.30)	4.50 (8.30)	21.40 (12.90)
130–139	28.00 (13.10)	17.90 (9.10)	15.30 (9.70)	23.20 (9.50)
140–149	26.50 (8.00)	11.60 (4.50)	29.10 (8.80)	17.50 (9.70)
150–159	15.00 (6.00)	6.20 (4.00)	23.40 (8.60)	11.90 (4.60)
160–169	11.00 (5.00)	3.20 (4.20)	13.00 (3.80)	8.00 (5.20)
170–179	5.60 (3.80)	1.50 (2.70)	7.30 (4.60)	4.40 (4.80)
180–199	2.30 (2.50)	0.53 (1.04)	5.40 (5.30)	1.73 (1.80)
200–220	0.23 (0.42)	0.05 (0.18)	0.39 (0.68)	0.07 (0.10)
Overall mean h	146 (6)	128 (7)	151 (7)	139 (9)
Total monitoring time (min)	1140 (243)	1006 (184)	1119 (243)	1131 (259)

Values are means (±SD).

day). When adjusted for age, heart rate was not significantly related to body weight, length, body mass index, or sum of skinfolds. Approximately 58% of the variability in heart rate could be accounted for by feeding mode, sex, and age; energy intake and SMR did not account for any more of the variability in heart rate beyond that explained by feeding mode, sex, and age (Table 3).

Minute-to-minute heart rates (bpm) for individuals were regressed against corresponding rates of energy expenditure (kcal/min) during sleep; individual correlation coefficients ranged from 0.01 to 0.70. The wide range of correlation coefficients was caused by varying levels of activity among infants during sleep. A dynamic range of energy expenditure and heart rate was required to detect a significant correlation.

DISCUSSION

The mean 18-h heart rate of breast-fed and formula-fed infants was a function of age, as expected, and feeding mode. An unexplained sex effect was detected at 4 months. Although the present study design did not address causality, we speculated that the differences in heart rate observed between feed-

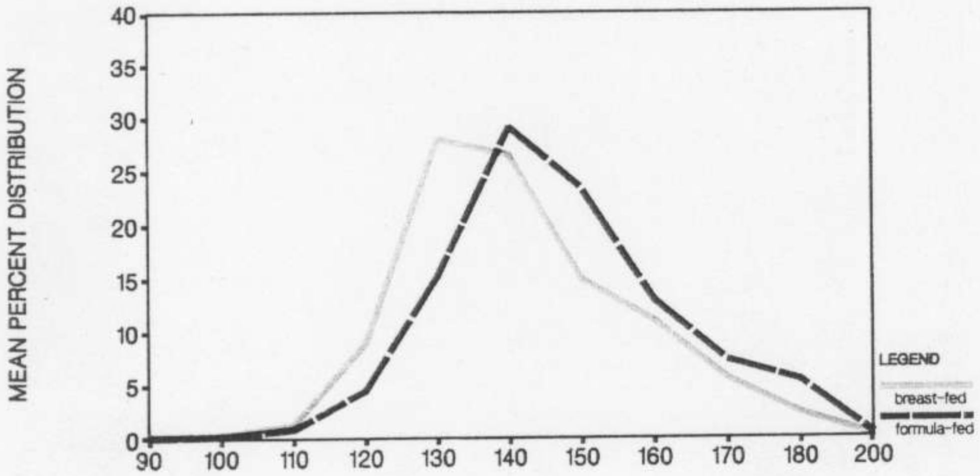

FIG. 1. Heart rate distribution of breast-fed and formula-fed infants at 1 month of age.

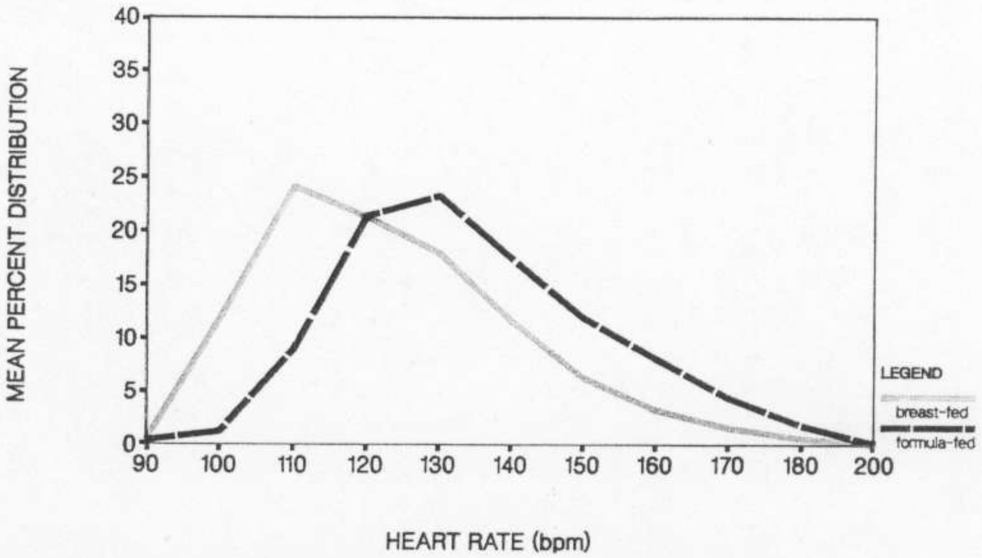

FIG. 2. Heart rate distribution of breast-fed and formula-fed infants at 4 months of age.

ing groups were caused by differences in energy intake, the composition of human milk and bovine milk-based formulas, physical activity, sleep patterns, or maturation of cardiovascular and autonomic nervous systems.

An independent effect of energy intake on heart rate beyond that explained by feeding mode, sex, and age was not demonstrated in our multiple variable model. Heart rate may be affected acutely by feeding and chronically by nutritional state. Benedict observed distinctly higher heart rates after feeding from those during minimum metabolic activity (2). Average heart rates of infants have been shown to be depressed during malnutrition (120 bpm), increased during recovery (148 bpm), and diminished after recovery (131 bpm) (9). In studies of suckling rats, nutrient deprivation resulted in a 40% reduction in heart rate that was dependent on a baroreceptor-mediated reduction in β-adrenergic cardiac drive and vagal restraint (10). We have reported the energy intake of breast-fed infants to be 12% and 30% lower than that of formula-fed infants at 1 and 4 months of age, respectively (4,5). Differences between feeding groups also entail differences in the intakes of most other nutrients and bioactive components present in human milk and absent from formulas (11). The lowered energy intake, however, appears to be physiologically regulated and therefore unlikely to represent evidence of undernutrition. The effects of augmented milk production on milk intakes of exclusively breast-fed infants studied for a short term (12) and the constant energy intakes of breast-fed infants before and after the addition of supplementary foods studied long term (13) indicate that intakes are not regulated by maternal factors affecting milk production.

Somewhat surprisingly, heart rate did not correlate with SMR, MOEE, or TDEE. Our inability to

TABLE 3. *Prediction of heart rate from age, sex, feeding mode, energy intake, and sleeping metabolic rate*

Independent variable(s) entered into model	R^2 (adjusted)	p value (partial coefficients)				
		Age	Sex	Feed	EI	SMR
Age	43.4					
Sex	0.0					
Feeding mode	12.3					
EI (kcal/kg/d)	34.4					
SMR (kcal/kg/d)	4.3					
Age, sex, feeding mode	58.4	.000	.117	.001		
Age, sex, feeding mode, EI	58.0	.000	.107	.015	.457	
Age, sex, feeding mode, SMR	58.0	.000	.101	.004		.461

EI, energy intake; SMR, sleeping metabolic rate.

detect a significant correlation may have resulted from the limited range of energy expenditure among these infants (coefficient of variability ~10%). Although metabolic demand is the major contributor to the circulatory load, it is not the only one. Moreover, the cardiovascular system responds to changes in demand not only through changes in heart rate, but also through variations in blood pressure, stroke volume, and the volume of blood in circulation.

Physical activity and sleep patterns also may explain some of the variability in heart rate observed between feeding groups. Although significant developmental changes occur, arousal state exerts a primary influence on heart rate throughout infancy (14). Heart rate is consistently highest and most variable during waking and lowest during quiet sleep. The sleep/wake patterns of infants have been demonstrated to depend on feeding mode; the transition from short (4–5 h) to longer periods of sleep (8–10 h) appears to be a function of weaning, not age (15). Breast-fed infants have been described both as more (16,17) and less (18) irritable than formula-fed infants. Others suggest that breast-fed infants are "more alert and active" than formula-fed infants (19–21). Differences in the ages of infants studied and a lack of relevant feeding information in many of these studies limit the interpretation of their results. More recently, Jensen et al. (22) demonstrated that breast-fed infants spend significantly more time in nonrapid eye movement sleep than do formula-fed infants.

Significant declines in heart rate after the first 4–8 weeks of extrauterine life coincide with changes in both sympathetic and parasympathetic tone (1). The fall in heart rate coincides with the postnatal decline in blood pressure, plasma catecholamines, and plasma renin activity. Heart rate normally increases from a mean of 123 bpm on the first few days of life to a maximum of 149 bpm between 1 and 2 months of age and then slowly declines. Our mean values were consistent with values cited at 1 month, but slightly lower than those at 4 months of age (134 vs. 141 bpm) (1). The cause of the decline in heart rate is unknown, but probably associated with the immaturity of the sympathetic nervous system at birth. Developmental changes in, and the variability of, heart rate may reflect alterations in the intrinsic rate of the denervated heart, in the level of adrenergic control, and in the level of cholinergic control (23). Circulating catecholamines play a major role in the adrenergic control of the immature cardiovascular system. Increasing vagal cardiac control after the first 4–8 weeks of extrauterine life is partially responsible for the developmental changes in heart rate. Diminished ventricular diastolic compliance with a relatively fixed stroke volume accompanied by dependence of cardiac output on heart rate has been proposed as the mechanism for high heart rate at birth; this rate decreases as ventricular compliance increases with age (1). Maturational differences may exist between breast-fed and formula-fed infants, although we have no evidence to support this conjecture. The lower heart rates, higher heart period variability, and higher vagal tone reported by DiPietro et al. (3) in breast-fed compared with those in formula-fed infants studied 17–56 h postpartum, however, suggest that factors other than maturation are likely responsible for the differences in heart rate.

In summary, we have shown that the mean heart rates of breast-fed infants were lower than those of formula-fed infants at 1 and 4 months of age. Although the patterns of heart rate distribution were similar between feeding groups, the preponderance of values in the lower heart rate intervals resulted in lower mean values for the breast-fed infants. These results are compatible with our previous findings of differences in energy intake and expenditure between breast-fed and formula-fed infants. However, differences in heart rates observed between feeding groups could not be explained by differences in energy intake or expenditure.

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