Reproducibility of measurement of resting energy expenditure in prepubertal girls[1–3]

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ABSTRACT We determined the reproducibility of measuring resting energy expenditure (REE) and the effect on REE of spending the night before testing at home compared with in a clinical research center. We studied 19 prepubertal girls aged 6.0–10.1 y with a mean weight-for-height of 108% of ideal. REE was measured for 30 min with a metabolic monitor after 12 h of fasting on three consecutive mornings during two different hospitalizations 6 wk apart. The initial REE measurement of each hospitalization was obtained on admission and the second and third measurements were performed during the 3-d hospitalization. Energy intake was ad libitum and was recorded while the children were in the research center. Body composition was determined twice with dual-energy X-ray absorptiometry. No significant effect on REE of day within visit was found across visits. There was no significant difference between the initial REE measurement and the second and third measurements. The mean REEs for the two hospitalizations were highly correlated. The mean CV in intraindividual REE (ie, all six measurements) was 5.8% and was unchanged when adjusted for fat-free body mass (FFM) or body weight. The mean CV in interindividual REE decreased when adjusted for FFM or body weight. Because REE was highly reproducible, a single measurement can suffice for energy expenditure studies in girls aged 6–10 y. Admission to a clinical research setting is not necessary for a reliable determination of REE. *Am J Clin Nutr* 1996;64:533–6.

KEY WORDS Energy expenditure, resting energy expenditure, children, reproducibility

INTRODUCTION

Obesity can be caused by either increased food intake or lower rates of total energy expenditure (TEE). Most studies of energy balance do not indicate a greater energy intake in obese children compared with that in normal-weight children. Studies in infants, children, and adults have shown that a lower rate of TEE is a predictor of weight gain (1–3). Reductions in TEE may enhance susceptibility to obesity in an environment that promotes food intake and inactivity. Because resting energy expenditure (REE) accounts for 60–75% of daily TEE, alterations in REE may have a major effect on TEE. An accurate assessment of REE is thus essential to the determination of TEE. Because the determination of REE is frequently relied on as a method for estimating daily energy needs in population studies (4) as well as in the clinical management of obesity, it is important to identify sources of variation due to methods to increase the reliability and precision of this measurement.

One methodologic consideration that has been examined in studies of adults and children is the influence of the environmental setting preceding the determination of REE (5–7). Most laboratories measure REE on an outpatient basis, ie, the subjects are brought to the laboratory on the testing day and the measurement is performed after a short period of recumbency in a relaxed environment. In contrast, depending on the facilities available, a few laboratories have measured REE after subjects stayed overnight in a clinical research center. The latter approach is expensive, time consuming, and inconvenient for both subjects and investigators, and could result in elevated REE values because of a lack of sleep as a result of an unfamiliar bed and a foreign environment.

The term *resting energy expenditure* will be used in this paper as the equivalent of basal metabolic rate and resting metabolic rate, although there are clear differences between the two measurements. Basal metabolic rate (inpatient REE) is measured 10–12 h after the last meal, subsequent to awakening in the same room, resting quietly at normal ambient and body temperature, and in the absence of either physical or psychologic stress before the measurement (8). The same conditions apply to resting metabolic rate (outpatient REE) except that the subject does some physical activity, mainly walking, before the measurement.

Because neither the reproducibility of REE in children nor the effect on REE of spending the night before measurement at home (ie, outpatient studies) compared with at a clinical research center have been determined, this study was undertaken to determine the reproducibility of REE measurements in normal-weight prepubertal girls and to determine whether there is a difference between inpatient and outpatient measurements.

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These objectives were met by measuring REE repeatedly during two different hospitalizations. Preliminary results of this study were presented previously (9).

SUBJECTS AND METHODS

Subjects

This study was conducted as a subproject of a larger investigation funded by the National Institutes of Health of metabolic predictors of weight gain in normal-weight, prepubertal girls. In the present study, 19 healthy girls aged 6.0–10.1 y were studied between May and November 1994. The girls weighed < 120% of ideal body weight–for-height as established by standards from the National Center for Health Statistics (10). All girls were prepubertal, Tanner stage 1 (11). They were not consuming special diets, participating in extreme exercise programs, or taking any medications. The children were recruited from schools in the Birmingham area. Before enrollment, each child was familiarized with the procedures and equipment used in REE analysis through a demonstrative interview. At that time, children were instructed to fast for 12 h before admission to the hospital. The purpose and inconvenience of the study were explained to children and parents before informed written consent or assent was obtained. This study was approved by the Institutional Review Board of the University of Alabama at Birmingham.

Experimental design

REE was measured for 30 min with a Deltatrac metabolic monitor (SensorMedics, Yorba Linda, CA). Children were studied on three consecutive mornings after 12 h of fasting during two different hospitalizations 6 wk apart. While at home, the children consumed an unrestricted diet and performed free-living physical activity. The children also consumed energy ad libitum in the research center. The first REE measurement was taken the first morning upon admission to the clinical research center (outpatient measurement). The second and third REE measurements were taken while the children resided in the research center (inpatient measurements).

On the first day of the study, the girls arrived by car at 0700 after 12 h of fasting and were admitted to the General Clinical Research Center of the University of Alabama at Birmingham. All children were carefully instructed about the procedures of the test and were asked to stay quiet. After 15 min of acclimation (rest in a hospital bed in a comfortable and temperature-controlled room), the first REE measurement was performed. A transparent plastic hood, connected to the system, was placed over the head. During the 30-min measurement period, the child rested quietly watching cartoons on television. Throughout the measurement, a researcher observed the girl to verify that she was relaxed but awake during the procedure. Special attention was given to prevent extra body movements. For subsequent REE measurements in the research center (days 2 and 3), the children were awakened but stayed in bed while the measurement was performed. Because of the timing of other tests involved in the protocol, children could not be randomly assigned to inpatient and outpatient conditions.

Energy expenditure

An open-circuit, computerized indirect calorimeter (Deltatrac; SensorMedics) connected to a transparent hood system was used. Briefly, room air was drawn through the transparent, ventilated canopy at a fixed flow rate (40 L/min). A constant fraction of the air flowing out of the hood was continuously collected and analyzed for oxygen and carbon dioxide by a differential paramagnetic sensor and an infrared carbon dioxide analyzer, respectively. The instrument was calibrated before each test for barometric pressure and with a standardized gas mixture (96.0% oxygen and 4.0% carbon dioxide). Oxygen consumption and carbon dioxide production were printed out at 1-min intervals, and the mean of the last 25 min was used to determine REE. REE was calculated using the formula of Weir (12). The Deltatrac machine calibration test was performed monthly with ethanol combustion.

Body composition

Dual-energy X-ray absorptiometry (DXA) (DPX-L; LUNAR Radiation Corp, Madison, WI) was used to assess body composition. The scan was analyzed using the pediatric software (LUNAR DPX-L) program for body composition analyses (version 1.5e) that uses a higher tube current and smaller collimation for greater contrast (13). The pediatric scan has been cross-calibrated against chemical analysis of a pig carcass in the pediatric body weight range (14). DXA allows for the determination of total and regional body compositions [fat and fat-free body mass (FFM)] and bone mineral density. The scan arm moves from head to foot and counts photon attenuation rates from the X-ray source within the table. During the scan, each child lay quietly on the table for 20 min. DXA involves minimal ionizing radiation (< 1 mSv).

Statistical analysis

The data were reported as percentages, means ± SDs, and CVs. The effects of day within visit and inpatient versus outpatient status on REE were evaluated using analysis-of-variance methods. The Pearson coefficient of correlation (r) was used to compare the mean REE between the two visits for each child. REE results were adjusted for FFM and body weight with regression models in the SAS package (15).

RESULTS

The mean age (± SD) of the 19 girls studied was 7.8 ± 1.2 y. Fifteen of the girls were white and 4 were African American. The mean weight (± SD) of the girls was 27.52 ± 4.4 kg and their mean percentage of ideal weight-for-height was 108 ± 8%. Mean percentage fat (as estimated with DXA) was 27.1 ± 6.3 %. Mean measurements of REE (kJ/d) are presented in **Table 1**. None of the children's data were excluded from the analysis. No significant effect on REE of day within visit was found across visits. There was also no significant difference between the outpatient (day 1) and inpatient (days 2 and 3) measurements. Comparison of the mean REE in visit 1 with that for visit 2 is shown in **Figure 1**. The mean REE values for the two visits were highly correlated ($r = 0.85$, $P < 0.0001$). The mean CV in intraindividual REE was 5.8%, ranging from 1.9% to 9.9% within children (**Table 2**). The mean CV in interindividual REE was 9.1%, ranging from 7.8% to 11.9% (**Table 3**). The total CV of intraindividual REE did not change when adjusted for FFM or body weight. The total

TABLE 1
Resting energy expenditure measured in 19 prepubertal girls during two visits separated by 6 wk[1]

	Outpatient	Inpatient	Grand mean
		kJ/d	
Visit 1	253 ± 30	260 ± 21	258 ± 24
Visit 2	261 ± 22	262 ± 24	261 ± 24

[1] $\bar{x}$ ± SD, n = 19. Outpatient refers to the measurement taken on day 1 and inpatient is the mean of measurements taken on days 2 and 3. There were no significant differences between visits or between inpatient and outpatient status within a visit.

CV in interindividual REE decreased when it was adjusted for FFM or body weight to 8.4% or 8.0%, respectively.

DISCUSSION

This is the first study in children to show the reproducibility of REE in healthy, normal-weight prepubertal girls. Even though energy intake and physical activity were not controlled, our findings show that *1*) no effect on REE of day within visit was found, ie, there was no significant difference between the outpatient and inpatient measurements, and *2*) the mean REE was not significantly different during the two visits. The mean CV in intraindividual REE was 5.8% and did not change when adjusted for FFM or body weight.

The sample size of 19 subjects detected an effect size of 0.64 with a power of 0.8 at the two-sided 0.05 significance level. In other words, if the SD of REE is 24 (Table 1), the difference between the mean REE that could be detected with 80% power is 15 kJ/d (0.64 × 24). This is a 6% difference (15/260) in REE. We recognize that if one is interested in a change in REE of < 6% then the sample size in not large enough. Because we did not achieve that large a difference, we cannot reject the null hypothesis. Therefore, the sample size of 19 is based on primarily feasibility considerations rather than scientific considerations.

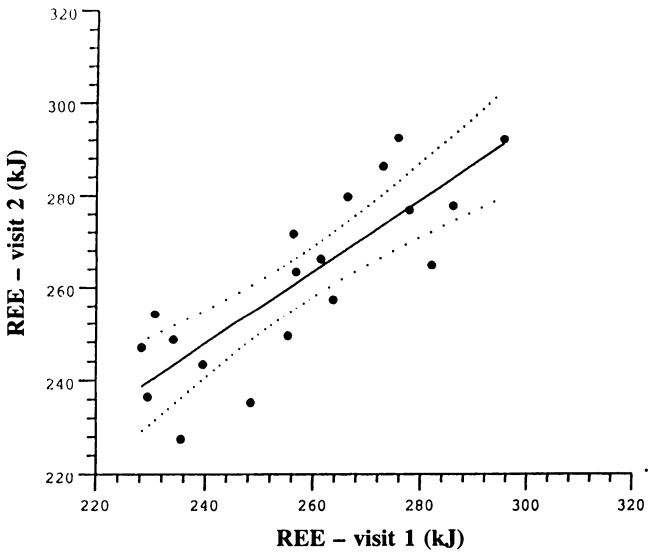

FIGURE 1. Comparison of mean resting energy expenditure (REE) as measured on the first and second visits. The dotted lines represent the 95% CIs. r = 0.85, P < 0.0001.

TABLE 2
CV of intraindividual mean resting energy expenditure (REE) in 19 prepubertal girls

CHILD	REE[1]	CV
	kJ/d	*%*
1	252 ± 20	7.9
2	233 ± 18	7.7
3	242 ± 24	9.9
4	273 ± 11	4.0
5	264 ± 5	1.9
6	238 ± 12	5.0
7	260 ± 16	6.2
8	242 ± 10	4.1
9	294 ± 14	4.8
10	264 ± 19	7.2
11	232 ± 12	5.2
12	241 ± 13	5.4
13	241 ± 18	7.5
14	280 ± 17	6.1
15	284 ± 27	9.5
16	277 ± 16	5.8
17	261 ± 12	4.6
18	282 ± 7	2.5
19	273 ± 13	4.8
Mean	—	5.8

[1] $\bar{x}$ ± SD. Measured on six occasions (three on each of two visits).

In contrast with studies in adults in which diet and physical activity were controlled (5, 6), in this study the children had ad libitum diets and activities, thus simulating their daily routines. One study in adults found that outpatient REE was 8.0% higher than inpatient REE (5); in our study these measurements were not significantly different. The investigators who found the difference stated that they do not have any evidence that the adult subjects violated the fasting conditions, which would be a possible explanation for the higher outpatient values (5). They commented that the higher values measured in the outpatient condition were due to the residual effects of an increased state of arousal, which did not decrease during recumbency preceding and during the tests. In another study, adult subjects underwent six randomized REE measurements; three measurements were made after the subjects slept the night before the measurements in their home and three measurements were made after they slept in a clinical research center (6). The

TABLE 3
CV of interindividual mean resting energy expenditure (REE) in 19 prepubertal girls

Visit and day	REE[1]	CV
	kJ/d	*%*
1: day 1	253 ± 30	11.9
1: day 2	256 ± 20	7.8
1: day 3	264 ± 22	8.3
2: day 1	261 ± 22	8.4
2: day 2	264 ± 23	8.7
2: day 3	259 ± 25	9.7
Mean	—	9.1

[1] $\bar{x}$ ± SD.

subjects walked about 50 m while in the clinical research center before the REE tests were performed. This was in contrast to our study in which the children were not allowed to do any activity before the REE measurements taken on days 2 and 3. However, similar to our findings, there were no significant differences in REE values between adult subjects who spent the night before the assessment in their own home and those who spent the night in a clinical research center (6). We concur with these investigators, who suggest that an inpatient visit is not necessary for a reliable measurement of REE provided that subjects are instructed carefully about the protocol (eg, a 12-h fast).

In another study, two different protocols for measurements of REE in 169 children aged 4–9 y were examined (7). Nineteen of these children were admitted to a research center and REE measurements were performed after the children were awakened (inpatient REE). The 19 children were also studied 2 wk later, at which time the measurements were performed in a postprandial state. In the postprandial protocol, children consumed their breakfast at home before going to the research center at ≈0900. In addition, for the postprandial protocol, 169 duplicate measurements were performed 2 wk apart. The REE of the 19 children was 11% higher when measured under postprandial conditions compared with inpatient REE measurements. The average CV of intraindividual REE in the 19 children was not reported. However, in the 169 duplicate measurements of postprandial REE, the average intraindividual CV was 5.4%, which is similar to our findings.

In one study premenarcheal girls aged 8–12 y were admitted to a clinical research center the evening before the first measurement of REE (16). The next morning, after a 12–14-h fast, the children walked ≈5 min before the measurements. The second REE measurements were obtained on an outpatient basis. Therefore, the children performed physical activity (walked) before both REE tests. There was no significant difference between the first and second measurements. The investigators speculated that measurements obtained on inpatient subjects who do not perform any physical activity before the REE measurement may differ from outpatient REE measurements. Our data do not support this speculation.

In our study the children could not be randomly assigned to inpatient and outpatient conditions because of the timing of other tests involved in the protocol. The outpatient REE was done first and was not significantly different from the inpatient REE. Thus, apprehension associated with the novelty of testing conditions did not appear to increase REE measurements. There was no difference between the first inpatient REE, after the subjects had spent the first night in an unfamiliar bed and foreign environment, and the second inpatient REE. Further, there was no difference between the results during visits 1 and 2. Therefore, no order effect was observed. It is possible that our results were not significantly different because the children were familiarized with the procedures and equipment used in the REE analysis and had fasted for 12 h before the tests and because the conditions during the test were rigorously controlled.

In summary, outpatient REE was not significantly different from inpatient measurements of REE in healthy, normal-weight prepubertal girls under otherwise identical study conditions. Because REE was highly reproducible, the results suggest that a single measurement of REE in the outpatient setting is suitable for energy studies in young girls. Admission to a clinical research center is not necessary for a reliable determination of REE. Because our study consisted of a homogeneous group of normal-weight girls aged 6–10 y, future studies should be extended to other age and sex groups.

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REFERENCES

1. Roberts SB, Savage J, Coward WA, Chew B, Lucas A. Energy expenditure and intake in infants born to lean and overweight mothers. N Engl J Med 1988;318:461–6.
2. Griffiths M, Payne PR. Energy expenditure in small children of obese and nonobese parents. Nature 1976;260:698–700.
3. Ravussin E, Lillioja S, Knowler WC, et al. Reduced rate of energy expenditure as risk factor for body-weight gain. N Engl J Med 1988;318:467–72.
4. World Health Organization. Energy and protein requirements: report of a joint FAO/WHO/UNU expert consultation. World Health Organ Tech Rep Ser 1985;724:71.
5. Berke EM, Gardner AW, Goran MI, Poehlman ET. Resting metabolic rate and the influence of the pretesting environment. Am J Clin Nutr 1992;55:626–9.
6. Turley KR, McBride PJ, Wilmore JH. Resting metabolic rate measured after subjects spent the night at home vs at a clinic. Am J Clin Nutr 1993;58:141–4.
7. Goran MI, Nagy TR. Effect of the pre-testing environment on measurement of metabolic rate in children. Int J Obes 1995;20:83–7.
8. Bursztein S, Elwyn DH, Askanazi J, Kinney JM. Energy metabolism, indirect calorimetry, and nutrition. Baltimore: Williams & Wilkins, 1989.
9. Figueroa-Colon R, Franklin FA, Goran MI, Lee JY, Aldridge R, Weinsier RL. Reproducibility of resting energy expenditure (REE) in prepubertal females. J Invest Med 1995;43:243A (abstr).
10. Hamil PVV, Drizd TA, Johnson CL, Reed RB, Roche AF, Moore WM. Physical growth: National Center for Health Statistics percentiles. Am J Clin Nutr 1979;32:607–29.
11. Tanner JM. Growth at adolescence. 2nd ed. Oxford, United Kingdom: Blackwell, 1962.
12. Weir JB. New methods for calculating metabolic rate with special reference to protein metabolism. J Physiol 1949;109:1–9.
13. Lunar Radiation Corp. LUNAR operation manual. Version 1.5e. Madison, WI: Lunar Radiation Corp, 1993.
14. Pintauro SJ, Nagy TR, Duthie CM, Goran MI. Cross-calibration of fat and lean measurements by dual-energy X-absorptiometry to pig carcass analysis in the pediatric body weight range. Am J Clin Nutr 1996;63:293–8.
15. SAS users guide: statistics; version 5 ed. Cary, NC: SAS Institute Inc, 1985.
16. Bandini LG, Morelli JA, Must A, Dietz WH. Accuracy of standardized equations for predicting metabolic rate in premenarcheal girls. Am J Clin Nutr 1995;62:711–4.