Variability of measured resting metabolic rate[1–3]

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ABSTRACT

Background: The necessity of a 12-h fast before resting metabolic rate (RMR) is measured is often a barrier to measuring RMR.

Objective: We compared RMR measurements obtained in the morning and afternoon and across repeated days to elucidate the magnitude and sources of variability.

Design: Healthy men ($n = 12$) and women ($n = 25$) aged 21–67 y, with body mass indexes (in kg/m^2) ranging from 17 to 34 and body fat ranging from 6% to 54%, completed 4 RMR measurements. RMR measurements were made in the morning (after a 12-h fast and 12 h postexercise) and in the afternoon (after a 4-h fast and 12 h postexercise) on 2 separate days with the ventilated-hood technique. Body composition was assessed by dual-energy X-ray absorptiometry.

Results: Mean (± SE) afternoon RMR was significantly higher than morning RMR on both visit 1 (1593.5 ± 35.6 compared with 1508.0 ± 31.5 kcal/d; $P = 0.001$) and visit 2 (1602 ± 29.3 compared with 1511.4 ± 35.9 kcal/d; $P = 0.001$). The 2 morning measurements ($r = 0.93$) and the 2 afternoon measurements ($r = 0.93$) were highly correlated, and no significant differences between measurements were observed. The mean difference between the morning and afternoon measurements was 99.0 ± 35.8 kcal/d (6%).

Conclusions: Repeated morning and evening measurements of RMR were stable and highly correlated. Day-to-day measurements of RMR were not significantly different. RMR measured in the afternoon after a 4-h fast and exercise was ≈100 kcal/d higher than RMR measured in the morning. *Am J Clin Nutr* 2003;78: 1141–4.

KEY WORDS Resting metabolic rate, RMR, resting energy expenditure, REE, variability, indirect calorimetry, reliability, oxygen consumption

INTRODUCTION

Knowledge of resting metabolic rate (RMR) is important in clinical applications for defining appropriate nutritional support and determining caloric needs for energy balance and weight management (1, 2). For measurements of RMR to be optimally useful, health care professionals need to have confidence in the accuracy of the measurement and knowledge of the variability in repeated measures. The accuracies of a wide range of indirect calorimetry systems—including whole-room calorimeters, doubly labeled water, open-circuit Douglas bag methods, metabolic carts, ventilated-hood systems, and a handheld device—have been published (3–8).

Data on day-to-day variability in RMR are limited. In a classic sense, this variability (ie, test-to-test differences) is described as biological variability + instrumental variability + error. Many factors—including anxiety, diurnal variation, the thermic effect of food, elevated postexercise oxygen consumption, stimulants, and pharmaceuticals—can affect the measured metabolic rate (9–15). If these factors are not controlled for, a large and indeterminant additional component of variability—methodologic variability—would be added to the aforementioned model. Therefore, in an attempt to define conditions under which a measurement can be considered an RMR, standard conditions have been developed. Standard conditions for measuring RMR are generally defined as an 8–12-h fast and a 12-h abstinence from exercise.

Previous studies have reported within-subject, day-to-day CVs ranging from 2% to 10% of RMR (16–20). These variability estimates include all 3 of the aforementioned components of variability: biological, instrumentational, and error. There are a few references that allow us to assess the contribution of instrumentation variability. A study by Wells and Fuller (21) compared the results of repeated tests done with an infusion of gases with those of the Deltatrac MD 1 Metabolic Monitor (Datex, Helsinki). Between-study reproducibility differed < 2% for oxygen uptake and energy expenditure (21). Phang et al (7) found that the error in oxygen uptake was 1.9% with the Deltatrac Metabolic Monitor and 3.2% with the model 2900 Metabolic Cart (SensorMedics, Anaheim, CA) when compared with a constructed lung model simulating carbon dioxide production and oxygen consumption. Quantification of the contribution of error is elusive. Factors contributing to error include human mistakes, inadequate validation, and methodologic errors.

Regardless of whether measured RMR is being used in clinical or nonclinical situations, health care professionals must be aware of the inherent variability in repeated tests to allow for appropriate interpretation and application. This is becoming increasingly important as technologic advances make measurements more accessible. Thus, measurement conditions are likely to deviate from the current standard methods. Specifically, measurements may be scheduled throughout the day. It is important to understand how measurements taken throughout

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TABLE 1
Subject characteristics[1]

	Women (n = 24)	Men (n = 10)
Age (y)	36.9 ± 11.7	40.0 ± 10.9
Weight (kg)	68.0 ± 12.2	78.2 ± 9.5
BMI (kg/m^2)	25.1 ± 4.9	25.3 ± 2.7
Percentage body fat (%)	32.2 ± 10.6	20.7 ± 10.1

[1] $\bar{x}$ ± SD.

the day vary and to quantify the differences in metabolic rate measured under less stringent conditions.

The present study was conducted to assess the variability in repeated measurements of RMR within a single day and across days. We also sought to evaluate the contribution of a midday meal on afternoon RMR. More specifically, the following hypotheses were investigated.

1) Repeated measurements of RMR on 2 d in either the morning or afternoon will be highly reliable and not significantly different.
2) RMR measured in the morning (after a 12-h fast and a 12-h abstention from caffeine, 12 h postexercise) and RMR measured in the afternoon (after a 4-h fast and a 4-h abstention from caffeine, 12 h postexercise) will not be significantly different.
3) Differences between morning and afternoon RMR measurements will be independent of the dietary characteristics of the midday meal (calories, carbohydrate, protein, and fat).
4) The relation between RMR and fat-free mass (FFM) measured in the morning and afternoon will be comparable.

SUBJECTS AND METHODS

Subjects

Thirty-seven (12 men, 25 women) healthy adults participated in the study; complete data were obtained for 34 subjects (10 men, 24 women). The subjects had a broad range of body mass indexes (BMI: 17–34; in kg/m^2) and body fat (5.5–54%). Pregnant women were excluded from participation. Descriptive characteristics of the study subjects are presented in **Table 1**. The study protocol was approved by the Colorado Multiple Institutional Review Board at the University of Colorado Health Sciences Center, Denver. All subjects provided written informed consent.

Experimental design

RMR was measured on 4 occasions. Two measurements were obtained in the morning between 0700 and 1000 under standard experimental conditions (after a 12-h fast and a 12-h abstention from caffeine, 12 h postexercise), and 2 measurements were obtained in the afternoon between noon and 1600, under less stringent conditions (after a 4-h fast and a 4-h abstention from caffeine, 12 h postexercise). For a given subject, morning and afternoon measurements were not necessarily performed on the same day, but all 4 measurements were obtained within a 2-wk period. Sixty percent of the morning and afternoon tests were performed on the same day and were not significantly different from those measured within a 2-wk period (P = 0.154). On the days that the afternoon measurements were obtained, subjects recorded their food intake (eg, breakfast) before the 4-h fast. Body composition was determined by dual-energy X-ray absorptiometry (DXA). Dietary recalls were used before the afternoon measurements were made to estimate energy and macronutrient intakes.

Measurements

Resting metabolic rate

RMR was measured by using indirect calorimetry and the ventilated-hood technique (model 2900 Metabolic Cart; SensorMedics). Subjects drove to the research laboratory and took the elevator to the testing room. Subjects were asked to refrain from food and beverage consumption (including caffeine) for 4 h before the afternoon measurements were made. A questionnaire (dietary recall) was used to confirm adherence to these guidelines (*see* Energy and Macronutrient Intakes below). For the morning measurements, subjects rested for 30 min in the supine position. For the afternoon measurements, subjects rested for 15 min. Subjects were also asked to refrain from nicotine consumption for 1 h before testing. Before each test, duplicate calibrations were performed on the flow meter with the use of a 3.0-L syringe and on the gas analyzers by using verified gases of known concentrations. Subjects rested quietly in the supine position in an isolated room with the temperature controlled to 21–24° C. RMR was measured for 15–20 min. Criteria for a valid RMR was a minimum of 15 min of steady state, determined as a $<$ 10% fluctuation in oxygen consumption and $<$ 5% fluctuation in respiratory quotient. Oxygen consumption and carbon dioxide production were used to calculate RMR according to the formula of de Weir (22).

Body composition

Body composition was determined by using DXA. Measurements were obtained while subjects were in the supine position by using a Lunar DPX-IQ bone densitometer (Lunar Corp, Madison, WI). The analysis was performed by using Lunar software version 4.3c (extended research analysis option).

Energy and macronutrient intakes

On the day that the afternoon measurements were obtained, subjects recorded their food and beverage intakes using a dietary recall form. Subjects were asked to record all food and beverages consumed from the time they awakened until the time they arrived in the laboratory. Subjects were asked to record all foods consumed, the method or means of preparation, the quantity, and the estimated portion sizes. In the presence of the subject, the dietitian reviewed the dietary recall for completeness, and any necessary clarifications were made. Energy and macronutrient contents were determined by using FOOD INTAKE ANALYSIS SOFTWARE (version 3.98; University of Texas Health Sciences Center, Houston).

Statistical analysis

The SPSS statistical package (version 10; SPSS Inc, Chicago) was used for data analyses. Means, SDs, SEMs, and absolute mean differences were calculated. The distributions of variables were examined for outliers that may have affected the

validity of subsequent analyses. Pearson's product-moment correlation coefficients were calculated to examine relations among the variables. Paired *t* tests were used to test for differences between 2 means (eg, mean RMR between visits 1 and 2). Repeated-measures analysis of variance (visit by time) was used to evaluate the main (visits and time) and interaction effects. Multiple regression analysis was used to determine potential predictors of differences between morning and afternoon RMRs, specifically to examine the relation between dietary intake and differences in RMR.

RESULTS

Reproducibility of repeated measurements of resting metabolic rate

Morning measurement: visit 1 compared with visit 2

The mean (± SE) morning RMRs measured at visits 1 and 2 were 1508.0 ± 31.5 and 1511.4 ± 35.9 kcal/d, respectively ($P = 0.989$). The correlation coefficient for the morning measurements was $r = 0.86$. Across subjects, the mean of the absolute difference in RMR from visit 1 to visit 2 was 79.2 ± 11.7 kcal/d (95% CI: 55.8, 102.6 kcal/d). The intraclass correlation coefficient between the morning measurements was 0.94, which indicated a high degree of agreement.

Afternoon: visit 1 compared with visit 2

The mean (± SE) afternoon RMRs measured at visits 1 and 2 were 1593.5 ± 35.6 and 1602.4 ± 29.3 kcal/d, respectively ($P = 0.687$). Afternoon measurements were highly correlated ($r = 0.90$). Across subjects, the mean of the absolute difference between visits was 77.9 ± 7.8 kcal/d (95% CI: 62.4, 93.4 kcal/d). The intraclass correlation coefficient of 0.92 suggests that repeated afternoon measurements were very reliable.

Resting metabolic rate: morning compared with afternoon

The mean RMR was 1509.7 ± 33.7 kcal/d for the morning measurements (visits 1 and 2) and 1597.9 ± 32.5 kcal/d for the afternoon measurements (visits 1 and 2). The afternoon RMR was significantly higher than the morning RMR ($P < 0.001$). The 2 measurements were highly correlated ($r = 0.90$). On visit 1, the mean of the absolute difference between the morning and afternoon RMRs was 105.4 ± 16.4 kcal/d. On visit 2, the difference was 109.5 ± 12.2 kcal/d. The absolute mean difference between the mean morning and mean afternoon measurements was 99 kcal/d, or an elevation of 6% (**Figure 1**).

Repeated-measures analysis of variance

Repeated-measures analyses of variance were performed to assess the effect of day (visit 1 and visit 2), time (morning and afternoon), and the day-by-day interaction. There was no significant visit effect ($P = 0.628$), which indicated that the RMR was not significantly different when measured at the same time on different days. However, the time effect was significant ($P < 0.0001$), which indicated that the RMR was significantly higher when measured in the afternoon. The day-by-time effect was not significant ($P = 0.807$), which indicated that the RMR was not significantly different when measured on different days at the same time of day.

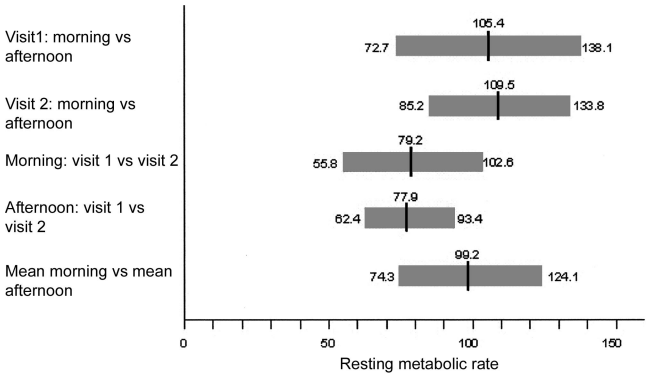

FIGURE 1. Variability in mean resting metabolic rate measured during the morning or afternoon of visits 1 and 2. 95% CIs for the absolute differences are shown.

Multiple regression analyses and correlation coefficients

Subjects ($n = 28$) recorded their dietary intake on a dietary recall form before the afternoon measurements were made. The dietary data appear in **Table 2**. Multiple regression analyses showed that dietary characteristics were not significant predictors of the differences in RMR from morning to afternoon. The difference in RMR between the morning and afternoon was poorly correlated with energy ($r = -0.50$), grams of protein ($r = -0.16$), grams of carbohydrate ($r = 0.14$), grams of fat ($r = -0.17$), percentage of protein ($r = -0.12$), percentage of carbohydrate ($r = 0.28$), and percentage of fat ($r = -0.27$).

Resting metabolic rate and dual-energy X-ray absorptiometry

FFM was highly correlated with RMR measured in the morning (visit 1: 0.80; visit 2: 0.75) and afternoon (visit 1: 0.72; visit 2: 0.72). Correlations between DXA and morning RMR were slightly stronger compared with the afternoon measurements.

DISCUSSION

Within-day and between-day RMR measurements are highly reliable. The CV for the difference between the morning measurements was 4.5%, between the afternoon measurements was 2.8%, and between the morning and afternoon measurements

TABLE 2
Dietary intakes reported on dietary recall forms before the afternoon measurements of resting metabolic rate[1]

Nutrient	Intake
Energy (kcal)	503 ± 210
Protein	
(g)	21.8 ± 11.7
(% of energy)	17.4 ± 7.4
Carbohydrate	
(g)	71.3 ± 29.2
(% of energy)	56.3 ± 16.9
Fat	
(g)	15.8 ± 10.8
(% of energy)	26.3 ± 14

[1] $\bar{x}$ ± SD; $n = 28$.

was 4.6%. Previous studies have reported within-subject, day-to-day CVs ranging from 2% to 10% (16–20).

RMR measurements repeated across days were not significantly different, and the absolute mean differences were < 80 kcal/d for both conditions. The afternoon RMR was significantly greater than the morning RMR on both visit 1 (85 kcal/d) and visit 2 (91 kcal/d). However, the absolute mean difference between the morning and afternoon measurements was only 99 ± 35.8 kcal/d. This difference is $\approx$6% of the mean RMR. When performing repeated measures of RMR, one would expect an afternoon RMR to be within 27–171 kcal/d of a morning RMR 95% of the time.

Multiple stepwise regression was used to assess the relation between dietary intake (energy, protein, carbohydrate, and fat) and differences in RMR. Dietary intake measured by a dietary recall did not predict differences in RMR. However, all subjects were tested 4 h postprandially. Previous research in this area indicates that the thermic effect of food should have a minimal effect by 4 h. Reed and Hill (15) observed 131 subjects for 6 h after they ingested meals of varying sizes and composition. They concluded that 60% of the thermic effect of food had been measured after 3 h, 78% after 4 h, and 91% after 5 h (15). Another study conducted by Weststrate (23) measured diet-induced thermogenesis for 4 h after a small meal. The patterns of the postprandial response indicated that in men and women the diet-induced thermogenesis response to a mixed meal with an energy content < 1500 kJ can be nearly completely assessed within 3 h (23). A 4- to 5-h fast may be adequate time to decrease the effect of the thermic effect of food on RMR measurements. Therefore, from a practical standpoint, in a group of subjects consuming a midday meal (500 ± 200 kcal), the size and composition of that meal will not adversely influence the accuracy of a measurement of RMR 4 h later.

Measurements on the same day and across days were reliable, and differences among measurements were not clinically significant. On the basis of these findings, it would be acceptable to measure RMR under conditions that are less stringent than the current standard conditions. Differences in measurements represent biologic error, instrument error, and pure error. Additional research is necessary to determine the contribution of each component.

On the basis of the results of the current study, we conclude that

1) RMR measured on 2 days (visits 1 and 2) under similar conditions will provide comparable results.
2) RMR measured in the afternoon will be significantly greater than RMR measured in the morning; the difference will be $\approx$5–6%.
3) RMR can be measured in the afternoon with the expectation that the measurement will be $\approx$100 kcal/d higher than the morning measurement.
4) FFM is significantly correlated with RMR measured in both the morning and afternoon.

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