Energy Measurements with the Room Calorimeter

Paul W. Moe
Agricultural Research Service, USDA

The research of this laboratory is directed to questions on energy use by humans, the variability among individuals, the nature of adaptation to change, and the development of the means to more precisely predict the energy needs of individuals and the value of foods. The focus of the laboratory is the calorimetry facilities which have evolved and expanded over ten years. These facilities were installed to provide the means to measure the energy expenditure of humans over 24-hr periods of time in an environment as comparable to free living as possible.

Facilities

Two Beltsville room-sized calorimeters provide the means to measure the energy expenditure (EE) of humans during 24-hour periods. EE is measured under controlled conditions which involve a full cycle of daily activities including three meals, sleep, physical activity and relaxation time. This protocol permits detection of specific sources of variation in energy expenditure associated with different diets and among individuals. Both calorimeters allow computation of EE from measurements of oxygen consumption and carbon dioxide production (i.e. indirect calorimetry). One of the calorimeters (Seale et al., 1991) is also a gradient-layer direct calorimeter which allows the physical measurement of heat emission through 80,000 thermocouples on the exterior surface of the inner wall of the chamber. Direct calorimetry provides an independent means to validate the computation of energy expenditure from respiratory exchange. Calorimetry facilities allow measurement of EE or heat emission under specific conditions. Calorimetry does not measure energetic efficiency or the energy value of foods although experiments may be designed so that estimates of energetic efficiency may be computed.

Dietary effects on energy use

A number of studies have involved the response to a reduction in energy intake. A major objective is to determine whether the body is able to adapt in any way that increases the "efficiency" of energy use or decreases the amount of energy needed to maintain the current body mass. Studies by Rumpler et al. (1991) followed the 24-hr EE of eight men during 4 weeks at intakes of 50% of requirements and during refeeding at weight maintenance. EE decreased during the period of reduced intake, but at a rate consistent with the decrease in body mass. There was some indication that the efficiency of use of body stores was increased during the weight loss.

Studies of substrate oxidation in those studies revealed a time effect in the metabolic response to changes in intake. Although fat oxidation increased and carbohydrate oxidation declined on the first day of reduced energy intake, carbohydrate oxidation was greater than during subsequent days at reduced intake. Similarly, upon refeeding several days were required to reestablish stable oxidation rates. The metabolic response when foods high in carbohydrates or fat are added to the diet were studied by Rumpler and Seale (1991). The addition of carbohydrate had a fat sparing effect whether the basal diet was high or low in fat. Also the addition of fat resulted in an increase in fat oxidation but only when added to a low fat diet at maintenance. These studies are being continued to identify the mechanism by which diet composition exerts an influence on body composition and on voluntary food intake.

Confusion in the literature over the magnitude of the thermic effect of food (TEF) and the variation among individuals was clarified by the work of Miles, et al. (1990) who found no circadian increase in EE during a 470 minute study. No correction for a circadian effect is needed for TEF studies and failure of the measured EE to return to baseline during TEF measurements, as is true of many reports in the literature, is a likely indication that those studies were too short.

Variation in energy expenditure

To what extent does the efficiency of energy use vary among individuals? That question is being resolved by studying the results of all calorimetry projects. Data from approximately 800 24-hr measurements with 130 different individuals will help resolve the question. Initial studies by Rumpler et al. (1990) showed a within-subject coefficient of variation of about 2.2% for 24-hr EE adjusted for physical activity. This is adequate to allow detection of relatively small differences among individuals. A specific test of a subject suspected of having an unusual energy expenditure was described by Tremblay et al. (1991). Although able to maintain weight with a reported energy intake of 1855 kcal/day, when confined to the room calorimeter for 5 days the mean energy expenditure was 3063 $\pm$80 kcal/d. Clearly the reported energy intake was not adequate for weight maintenance and the discrepancy was not due to an unusually low EE.

Howe et al. (1991) found no variation in resting energy expenditure (REE) when measurements were made when estradiol and progesterone fluxes were at basal or elevated levels. There were significant differences, however, when EE was measured for 24-hr and the differences appeared to be related to differences in the rate of EE during sleep.

Most studies conducted in the calorimeters to date have controlled the amount of physical activity in order to reduce the amount of variation among individuals to improve the precision of diet studies. Future studies are planned which will identify the amounts of metabolic substrates metabolized during exercise. Studies using doubly labeled water (DLW,$^2H_2{}^{18}O$) have been used to study the EE in environments ranging from the extremes of a Mt. Everest climb (Reynolds et al., 1992) to a saturation dive at 31 atmospheres (Seale et al., 1991). The methodology used in the DLW method was validated in intake-balance studies (Seale et al., 1990) and by simultaneous indirect calorimetry and DLW measurement of EE in subjects over a 7-day period (Seale et al., 1992).

Energy Value of foods

Calorimetry is not required to establish the metabolizable energy (ME) value of foods or to study the factors which influence the ME value of foods. ME is, however, frequently measured during calorimetry studies in order to precisely measure or control energy intake. Miles et al. (1988) compared several methods of computing ME values and compared the results to values actually measured for high and low fiber diets. The use of the specific Atwater factors was more accurate than use of the general factors or formulas of other researchers, overestimating the ME values by 6 and 4.6%, for high and low fiber, respectively. In further studies, Miles (1991) found good agreement between measured ME and predicted values by a variety of methods for low fiber diets, but larger errors associated with high fiber diets. These studies underscore the need to more precisely characterize the carbohydrate/fiber fraction of foods as it relates to energy value. It is also useful to remember that the energy value of a food is a description of the food and indicates the potential amount of energy available to humans. Circumstances such as illness or bowel disorders do not affect the potential ME value of a food but do affect the actual energy supply to individuals and must be dealt with separately.

References

Howe JC, Rumpler WV and Seale JL. 1991. Twenty-four hour energy expenditure in relation to the menstrual cycle. FASEB J. 5(6):A1648. (Abstract).

Miles CW, Kelsay JL and Wong NP. 1988. Effect of dietary fiber on the metabolizable energy of human diets. J. Nutr. 118. 1075-1081

Miles, CW, Wong NP, Rumpler WV, and Wells PA. 1990. Effect of circadian variation in energy expenditure on the thermic effect of food. FASEB J. 4:A381. (Abstract).

Miles C. 1991. The metabolizable energy of human diets differing in dietary fat and fiber measured in humans. J. Nutr. 122:306-311.

Reynolds, RD, Howard MP, Deuster P, Lickteig JA, Conway J, Rumpler W and Seale J. 1992. Energy intakes and expenditures on Mt. Everest. Faseb J. 6(4): A1084. (Abstract).

Rumpler WV, Seale JL, Bodwell CE and Conway JM. 1989. The long and short term effects of caloric restriction on energy expenditure in human subjects. Energy Metabolism in Farm Animals, E.A.A.P. Publ. 43:275-278.

Rumpler WV, Seale JL, Conway JM and Moe PW. 1990. Repeatability of 24 hour energy expenditure measurements in humans by indirect calorimetry. Am. J. Clin. Nutr. 51:147-152.

Rumpler WV and Seale JL. 1991. Energy expenditure and substrate oxidation in humans on high or high or low fat diets overfed fat or carbohydrate. FASEB J. 50:A1650. (Abstract).

Rumpler WV, Seale JL, Miles CW and Bodwell CE. 1991. Energy-intake energy restriction and diet-composition effects on expenditure in men. Am. J. Clin. Nutr. 53:430-6.

Seale JL, Rumpler WV, Conway JM and Miles CW. 1990. Comparison of energy expenditure estimations using doubly labeled water, intake balance, and direct/ indirect calorimetry methods in adult men. Am. J. Clin. Nutr. 52:66-71.

Seale JL, Rumpler WV, Conway JM, Thorp JW and Haberman KJ. 1991. Energy expenditure and water and urine production at the surface and during saturation dives at 5.5 and 31 atmospheres (ATA). Proc. 1991 Undersea and Hyperbaric Medical Society 18:94-95. (Abstract).

Seale JL, Rumpler WV and Moe PW. 1991. Description of a direct/indirect room sized calorimeter. Am. J. Physiol. 260:E306-E320.

Seale, JL, Conway JM and Canary JJ. 1992. Seven-day validation of doubly labeled water method using indirect calorimetry. J. of Appl. Physiol. (In press).

Tremblay A, Seale JL, Almeras N, Conway JM and Moe PW. Energy requirements of a postobese man reporting a low energy intake at weight maintenance. Am. J. Clin. Nutr. 54:506-508. 1991.