Subject Review

Resting Metabolic Requirements of Men and Women*

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The resting metabolic rates (RMRs) of 44 lean and obese women, 8 of whom were trained athletes, and of 60 lean and obese men were measured by indirect calorimetry. These healthy humans, ranging from 18 to 82 years old and from 43 to 171 kg in weight, were mentally and physically active. Body composition was determined by densitometry and skinfold thickness. Stepwise multiple regression analysis was used to determine whether one or several variables best predicted RMR. Body compositional variables reflecting active protoplasmic tissue were all highly interrelated. Body weight alone yielded prediction values for RMR comparable to those of other variables of active protoplasmic tissue mass. Among these mentally and physically active women and men, the influence of age on RMR was trivial, and regional distribution of fat had no influence on the RMR. The 95% confidence limits for RMR in both lean and obese subjects were broad. Thus, metabolic efficiency is not necessarily or exclusively related to obesity. In fact, the caloric requirements of humans, based on body weight or active protoplasmic tissue mass, may vary twofold. With the exception of the elderly men, the classic prediction equations and tables developed during the first half of this century greatly overestimated the RMR of healthy lean and obese humans. Therefore, new regression equations for predicting the RMR based on weight and fat-free mass were developed.

Much of the monumental work and many classic reports in the area of metabolism originated in the laboratories at the Mayo Clinic.[1,2] Therefore, it is fitting to review new results obtained from studying modern-day lean and obese men and women in the *Mayo Clinic Proceedings*.

The lowest, or the basal, metabolic rate occurs transiently during early morning hours of deep sleep.[3] In clinical practice, this transient basal rate has little influence on total energy requirements and is often impractical to measure. Another state of metabolism is the resting metabolic rate (RMR), which occurs while a person is resting and fasting. The RMR is the best predictor of the overall requirements and usually consumes approximately 65 to 70% of the daily energy requirements of most ambulatory humans;[4] it also reflects almost all energy requirements of bedridden hospitalized patients. Therefore, the RMR has relevance to active and inactive persons. The postprandial period is a state associated with augmented energy expenditure. The heightened metabolic state accompanying ingestion of food was initially noted as the specific dynamic action of food but is currently referred to as the thermic effect of food or, synonymously, as dietary-induced thermogenesis.[5] Another state of high-energy requirement is that associated with exercise-induced thermogenesis. In the average person, exercise-induced thermogenesis augments energy expenditure by about 20 to 30% over the RMR.[6] This state of energy expenditure varies widely, however, and can be voluntarily controlled in humans.

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My colleagues and I began measuring the RMR of healthy lean and obese humans so their results could serve as controls for the various disease states we were evaluating. As the data accumulated, it became evident that the measured RMRs for normal humans were less than their predicted rates based on the formulas and tables from the largest and most authoritative reports published during the first half of this century.[1,2,7-10] A reassessment of our measured RMRs based on body compositional variables, such as fat-free mass or body surface area, did not change our initial impression that the currently available regression equations and tables overestimate the RMR of both lean and obese humans. Therefore, we began a systematic study to reappraise the caloric requirements of lean and obese male and female subjects. The data reported herein substantiate that the classic information published in the first half of this century overestimates the RMR of lean and obese humans. In addition, the new data reveal that the caloric requirements per unit mass vary widely and are independent of leanness or obesity.

SUBJECTS AND METHODS

A profile of the study population is shown in Table 1. For the purpose of this study, obese persons were considered healthy, providing no evidence was found of any disease process, but they had excessive accumulation of adipose tissue.[11,12] The 104 healthy male and female subjects in this study constituted a heterogeneous population. They were young to old (18 to 82 years of age) and short to tall (150 to 188 cm in height); they were lean to obese (43 to 171 kg), and their body mass indices varied widely (18 to 59 kg/m^2). They were mentally and physically active and had broad socioeconomic, educational, and employment backgrounds. Caucasians, Blacks, and Mongolians were studied. They were consuming balanced meals, and their weights were stable.

Table 1.—**Physical Characteristics of the 104 Study Subjects**

No. of subjects	Sex	Age (yr)	Height (cm)	Weight (kg)	BMI* (kg/m^2)
44†	F	18-65	150-180	43-143	18-50
60	M	18-82	163-188	60-171	20-59

*BMI = body mass index.
†Eight were trained athletes.

Thus, the study encompassed a typical heterogeneous population characteristic of residents of a large metropolitan city in the United States.

Indirect calorimetry was used to measure the RMR in the morning after a 12-hour overnight fast. Respiratory gaseous exchange rates were measured with a Beckman metabolic cart (model MMCI). Each value is the mean of two or three measurements of five to six 1-minute values. Thus, data points are means of some 10 to 18 measurements. The measured RMRs were extrapolated to 24-hour resting metabolic requirements. The accuracy and reproducibility of indirect calorimetry in our experience have been published.[11] (The percentage variability of the gaseous exchange rate is 4% or less 95% of the time.) The RMR of humans can be accurately and reproducibly measured.

The energy requirements were plotted against body composition. The fat-free mass and the fat mass were determined by densitometric techniques.[13,14] Measurements of skinfold thickness were also used to estimate the fat-free mass and the fat mass.[15] Body surface area, body mass index, lean body mass, and body cell mass were calculated.[11,12] Stepwise multiple regression analysis was used to determine whether some combination of weight, height, age, fat mass or fat-free mass by densitometry, fat mass or fat-free mass by measurement of skinfold thickness, body surface area, body mass index, lean body mass, or body cell mass was a better predictor of RMR than a single variable.[16] Resistant regression equations were used to express the relationships among RMRs, carbohydrate, fat, and protein oxidation rates, and body weights.[17]

RESULTS AND DISCUSSION

Body compositional variables that reflect active protoplasmic tissue, such as weight, fat-free mass by densitometry or measurement of skinfold thickness, body surface area, body mass index, lean body mass, and body cell mass, are all highly interrelated (r>0.85). Therefore, currently it is extremely difficult, if not impossible, to identify which of these variables actually reflects active protoplasmic tissue[11,12]—especially when the limitations of these techniques are considered.[18] Nonetheless, the variables most highly, but comparably, correlated with the measured RMR are weight, body surface area, lean body mass, body cell mass, and fat-free mass by densitometry or measurement of skinfold thickness.[11,12] Combinations of variables in stepwise regression analysis to predict RMR, however, yielded values comparable to those for weight alone (r = 0.74) in predicting the RMR of humans.[11,12] Because weight is the most easily and accurately measured variable and is highly correlated with RMR of both men and women, it is an appropriate variable to use if estimates of RMR are needed for humans.[11,12] This observation does not deny the existence of minor differences among variables that reflect active protoplasmic tissues—specifically, fat-free mass.[19] Nonetheless, at this time, the weight of a person is the most practical measurement available and a good variable to use for predicting the RMR.

Perhaps finding that weight alone is a reasonable predictor of RMR is not surprising when one considers the vastly different energy requirements per unit mass of the various aerobic tissues (Table 2). The adult brain (which is mostly lipids rather than proteins) constitutes about 2% of the body weight and consumes about 20% of the RMR.[20-22] Similarly, the liver constitutes about 2% of the body weight and consumes an additional 20% of the RMR. Much of the energy consumption by the liver is used to synthesize glucose and ketone bodies as fuels for the brain. Collectively, the brain and the liver constitute only 4 to 5% of the total body weight but are responsible for approximately 40% of the RMR. Thus, a large portion of the RMR can be directly or indirectly related to the metabolic requirements of the nervous system. Muscle composes 35 to 40% of the body weight but accounts for only about 20% of the RMR.[20-22] Adipose tissue normally constitutes about 15 to 25% of the body weight but accounts for only 2 to 5% of RMR.[20-22] These disproportionate rates of energy requirements per unit mass of different tissues partly explain why weight correlates about as well with RMR as do the bulk masses of active protoplasmic tissue with their heterogeneous metabolic requirements. These considerations should be extended to obese and athletic humans. Although the absolute RMR is greater the heavier the man or woman, energy expenditure per kilogram of body weight for men and women is reduced as weight increases. Large variations in body weight occur, not because of differences in the amounts of high-energy-requiring brain and liver masses but because of large differences in the amounts of moderate-energy-requiring skeletal muscle masses, especially in athletes, or because of huge differences in the amount of low-energy-requiring adipose tissue masses, especially in obese humans. In essence, a major portion of the RMR in adults is relatively constant because of brain and liver metabolism; the increases in RMR per kilogram of body weight depend primarily on other body components, particularly skeletal muscle and adipose tissue.

Figure 1 displays the relationship between measured RMRs and body weights of modern-day adult men and women. The regression lines for men and women differ significantly ($P<0.05$) when weight is used as the variable. In contrast, within the male or female gender, the slopes of the regression lines for the RMRs for lean and obese men or for lean and obese women are statistically indistinguishable. Therefore, single regression lines (equations) with their 95% confidence limits are shown for predicting the RMR for nonathletic, healthy, lean and obese men (RMR = 879 + 10.2 kg weight) and for nonathletic, healthy, lean and obese women (RMR = 795 + 7.18 kg weight). The regression line for the athletic women (RMR = 50.4 + 21.1 kg weight) is clearly different from that for the nonathletic women ($P<0.05$), and the 95% confidence limits for the regression line for the athletic women are narrow. These current data and the newly derived prediction equations reflect that modern-day healthy humans have RMRs that are less than their predicted RMRs based on the equations and tables developed from the largest and most authoritative reports published during the first half of this century.[1,2,7-10,23] Other investigators have reported similar results.[24]

Because of the large variations in the RMR of humans, these prediction equations may over-

Table 2.—**Weight and Energy Requirements of Aerobic Tissues***

Tissue	Weight (%)	Energy requirements (%)
Brain	2	20
Liver	2	20
Muscle	35-40	20
Adipose	20	2-5

*Rates of energy requirements per unit mass of various body tissues are grossly disproportionate.

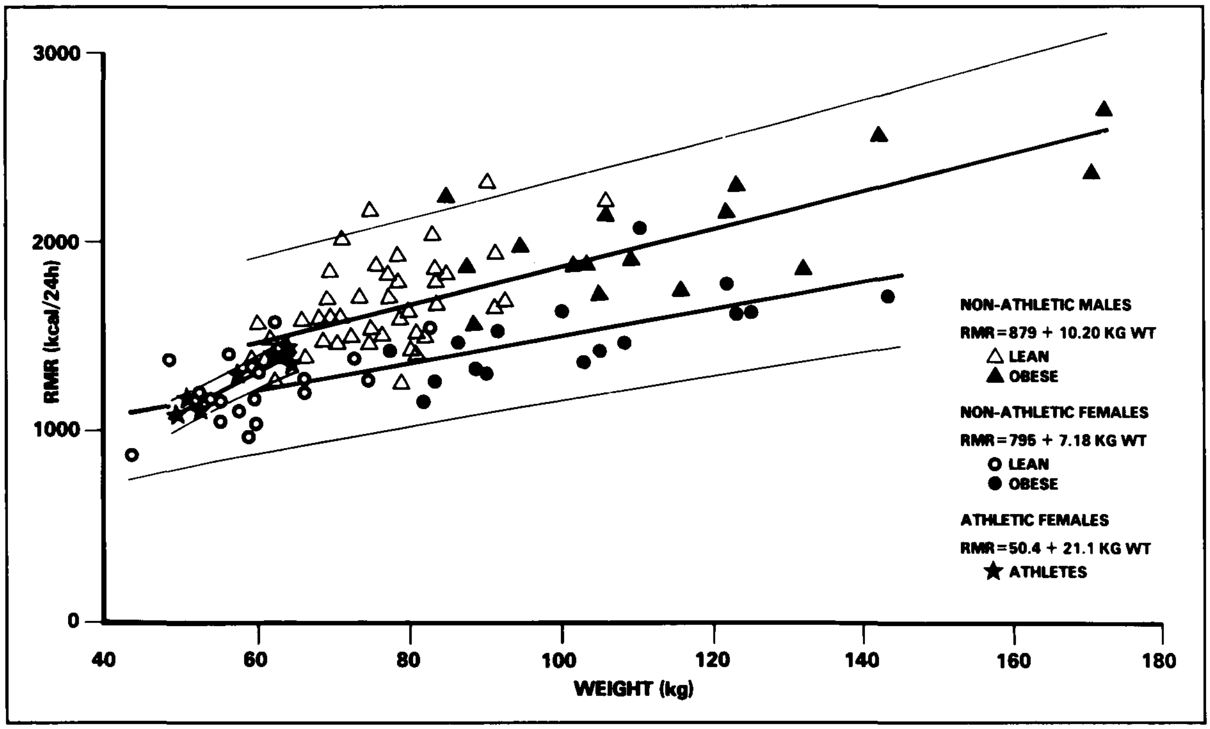

Fig. 1. Resting metabolic rate (*RMR*) of 44 women, 8 of whom were athletes, and 60 men plotted against body weight. Slope of regression line for men is statistically different from slope of regression line for women. RMR increases as weight increases in both men and women. Lighter lines above (men) and below (women) the regression lines represent the 95% confidence limits for the data.

estimate or underestimate the actual (measured) RMR of nonathletic men and women by about 20 to 30%. In contrast, close estimates can apparently be made for athletes. The predicted RMR of a well-trained competitive athlete estimates the RMR within 8 to 10% of the actual value. Athletic women have greater increases in RMR per gain in body weight than do nonathletic women (Fig. 1). Body weight is also more highly correlated with RMR among the female athletes (r = 0.94) than among the nonathletes (r = 0.74). Comparable data for athletic men are not available.

When weight is used as a variable to reflect RMR, gender has an influence on the slopes of the regression lines for male and female subjects (Fig. 1). An explanation for the difference in caloric requirements per kilogram of body weight for male and female subjects resides in the differences in body composition between the sexes.[12] As body mass increases, the relative proportion of stored triglycerides is greater in women than in men. Thus, per unit mass, relatively more inert triglycerides are stored subcutaneously as fat in women than in men, and the energy requirements per unit of fat mass are less than the energy requirements per unit of fat-free mass. When the RMR of adult humans is corrected for fat-free mass, however, the influence of sex is negated.[12]

Figure 2 shows the RMRs for men and women plotted against their fat-free mass determined by densitometry. The regression lines for the RMR and fat-free mass are indistinguishable between the male and female subjects. Therefore, a single regression equation can be used to estimate the RMRs of men and women if the fat-free mass is known (RMR = 186 + 23.6 kg fat-free mass determined by densitometry). The broad 95% confidence limits of the RMR per unit mass, however, are not reduced. Note in Figure 2 that within the 95% confidence limits the RMR per fat-free mass may vary twofold. This broad variance in energy requirements remains independent of leanness

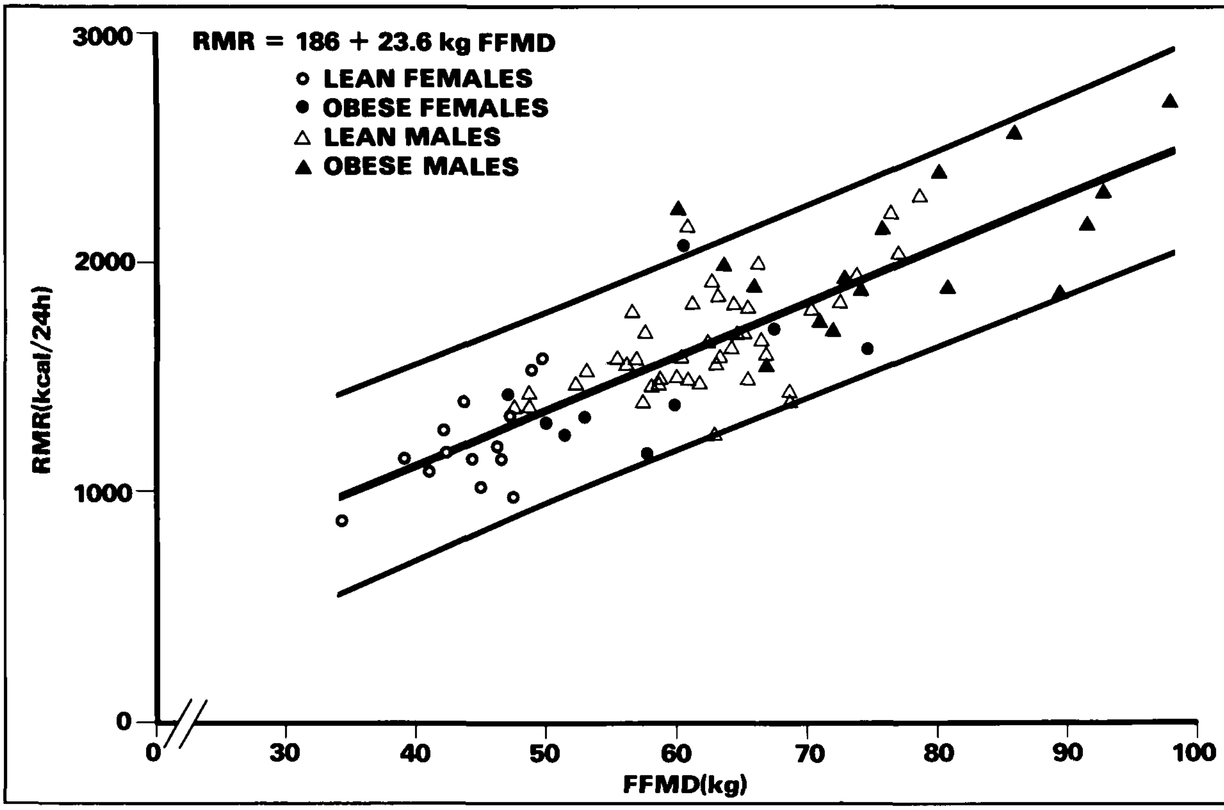

Fig. 2. Resting metabolic rate (*RMR*) of men and women plotted against their fat-free mass determined by densitometry (*FFMD*). Single regression equation shown can be used for both men and women.

and obesity even though the RMR is expressed in kilograms of fat-free mass. This fundamental observation that the resting caloric requirements of lean and obese adult men and women vary widely must be recognized if dietary management is an important component of therapy for the person who needs to gain weight (by means of hyperalimentation) or for the person who needs to lose weight (by means of hypoalimentation).

Figure 3 shows the RMR of female athletes plotted against their fat-free mass (RMR = 330 + 19.2 kg fat-free mass determined by densitometry).[11] Calculating the RMR based on fat-free mass eliminates the influence of being a well-trained athlete on the RMR. Thus, the RMR per unit of fat-free mass is not augmented by training. Although data from male athletes are not available, this lack of influence on the RMR probably extends to men as well. Regardless of how the data for athletes are expressed, however, the 95% confidence limits remain narrow for these selected world-class female athletes.

In addition to weight or body composition and gender, the influences of age on the RMR were evaluated in male and female volunteers. Without question, young, physically active persons consume more calories without gaining weight than do elderly, sedentary persons, but in the resting state, the inverse influences of age in elderly men (-3.3 ± 1.8 age in years) and women (-2.9 ± 2.3 age in years) who have normal brain, liver, and muscle function seem to be too small to be statistically significant among our limited number of volunteers.[11,12] The population of the United States is older and probably more active now than it was during the first half of this century. In the most commonly used formulas to estimate the RMR of men and women—the Harris and Benedict equations—age has major influences. Among today's population, use of the Harris and

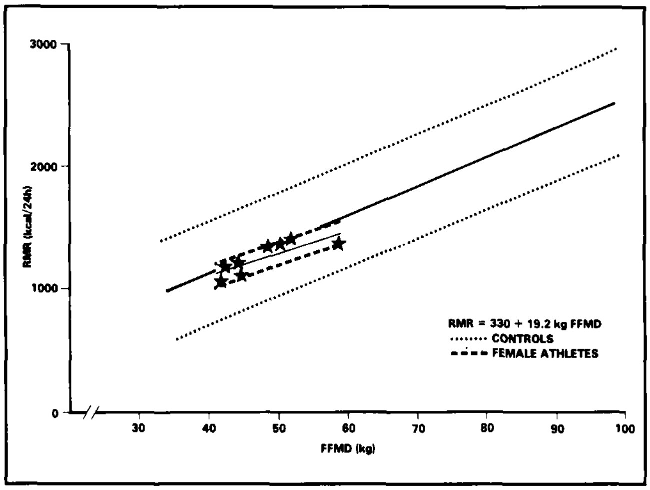

Fig. 3. Resting metabolic rate (*RMR*) of eight athletic women plotted against their fat-free mass determined by densitometry (*FFMD*). Note narrow 95% confidence limits (*dashed lines*) for these selected world-class female athletes.

Benedict equations grossly overestimates the caloric requirements of young persons and underestimates the caloric requirements of elderly persons.[12]

A relationship was also sought between regional fat distribution and the RMR.[12] Android (abdominal or apple-type) obesity is known to be associated with diabetes, hypertension, hyperlipidemia, and coronary artery disease;[25-29] therefore, the data were analyzed in an effort to disclose a relationship between regional fat distribution and resting energy requirements. Regional fat distribution expressed as an abdominal-to-hip ratio had no bearing on caloric requirements of adult humans.[12]

Indirect calorimetry not only reflects the energy requirements but also allows calculation of the quantities of carbohydrate, protein, and fat oxidized. Some investigators have suggested that obese persons have defective mobilization of stored triglycerides and therefore are predisposed to adiposity. Figure 4 shows the general trends of the nature and the quantity of fuels oxidized by 60 lean and obese men after an overnight fast in the resting state.[12] A continuum of caloric requirements was present from the lowest to the highest weights among these men; however, the quantities of carbohydrate, fat, and protein oxidized did not increase in parallel. The resistant regression equations used to display these trends in fuel oxidation showed that the contribution of fat derived from lipolysis for oxidation increased as body weight increased. Thus, as the weight of these men tripled, the rate of fat oxidation tripled. In contrast, the contribution of carbohydrate derived from glycogenolysis for oxidation was inversely related to body weight. Protein oxidation increased slightly with obesity. These data unequivocally reveal that fatty acid mobilization and oxidation are not impeded among persons who form a spectrum from very lean to massively obese.

CONCLUSION

The commonly used prediction tables and equations developed in the first half of this century overestimate the energy requirements of modern-day lean and obese adult men and women.[11,12] The resting energy requirements for persons of similar weight or fat-free mass may vary twofold. Therefore, if possible, the energy requirements of a person should be measured rather than estimated. The RMRs for men and women differ for

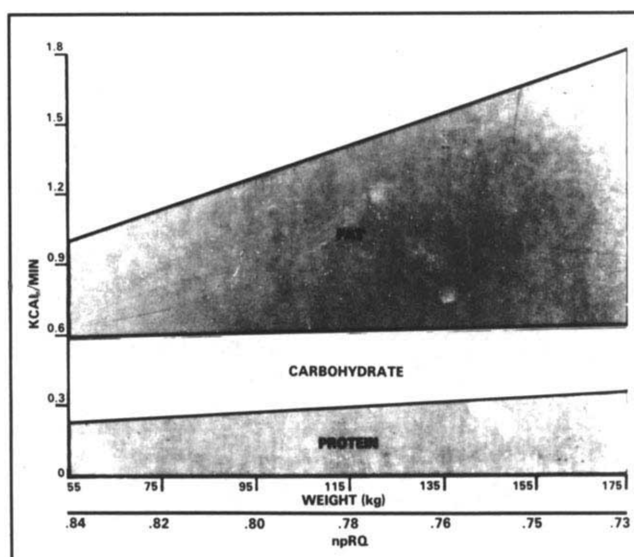

Fig. 4. Nature and quantity of fuels oxidized in 60 healthy lean and obese men after an overnight fast. The nonprotein respiratory quotient (*npRQ*) decreases as body weight increases. (From Owen and associates.[12] By permission of the American Journal of Clinical Nutrition.)

weight but are indistinguishable when based on fat-free mass. The influence of age on the RMR is trivial, and regional fat distribution seems to have no effect on RMR. As obesity progresses, the quantity of free fatty acid mobilized and oxidized increases, and fat oxidation does not seem to be impaired in obesity.

For future investigations, the broad variance in the RMR of healthy humans should be analyzed. Male and female nonathletes have wide 95% confidence limits for RMR (shown in Figures 1 and 2), a reflection of the fundamental fact that the resting caloric requirements of both lean and obese men and women are broad. Humans are heterogeneous in regard to their caloric requirements, and this variation in metabolic efficiency during the fasting, resting state is independent of leanness or obesity.[11,12]

Foods are eaten and their energy content is used to generate adenosine triphosphate (ATP) and heat by reducing oxygen with electrons and protons. Through orderly biochemical oxidative processes, the high-energy electrons trapped in carbohydrates, fats, and proteins are transferred along an electron-transport chain embedded in an ion-impermeable inner mitochondrial membrane to oxygen. The energy released by the transfer of electrons down this transport chain is harnessed to generate ATP needed to drive biochemical reactions. The number of high-energy phosphate bonds produced in ATP per mole of oxygen consumed is commonly known as the phosphate-oxygen ratio (P:O ratio). The efficiencies at which the free energies released from the oxidation of carbohydrate, fat, and protein are trapped in the pyrophosphate bonds of ATP and the subsequent efficiency at which the energies released from the cleavage of the pyrophosphate bonds are used to perform in vivo functions must vary much more than generally recognized if the caloric requirements for humans per unit mass are very broad. Furthermore, the quantity of chemical energy initially or subsequently passed across the outer mitochondrial membrane as protons to reduce oxygen and generate heat from macronutrients must also have wide ranges among humans. Mitochondrial metabolism in humans, and in particular the energetics of ATP and heat generation, need to be reevaluated if the energy requirements and proper nutrition of humans are to be understood.

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