Energy Requirement for Long-Term Body Weight Maintenance in Older Women

Wayne W. Campbell, Deanna Cyr-Campbell, James A. Weaver, and William J. Evans

The total dietary energy requirement of healthy, free-living older women was examined by determining the total energy intake (TEI) required for long-term body weight maintenance in nine women aged (mean ± SD) 67 ± 9 years (range, 56 to 78). For 14 weeks, each woman consumed defined amounts of foods and beverages prepared at a General Clinical Research Center (GCRC) to provide 0.8 g protein · kg^{-1} · d^{-1} and a nonprotein energy ratio of 40% fat to 60% carbohydrate. Adjustments to TEI were made to keep body weight within ±0.5 kg of each woman's starting body weight. All women were asked to maintain their habitual level of daily activity, and the energy cost of physical activity was estimated using the Yale Physical Activity Survey (YPAS). Resting energy expenditure (REE) was measured with each woman in the postabsorptive state just after awakening, using an indirect calorimeter at baseline and week 14. The energy requirement expressed as the ratio of TEI to REE was 1.82 ± 0.15, a value 21% higher ($P < .001$) than the energy allowance of 1.5 × REE suggested for women beyond age 50 years in the 1989 Recommended Dietary Allowances (RDAs). Using the RDAs equation to predict REE from body weight (pREE), the ratio of TEI to pREE was 1.73 ± 0.18 ($P < .005$, comparison with 1.50 × REE). Estimates of the energy expenditure for physical activity (EEPA) based on the energy intake-balance data and the YPAS data were similar (3.18 ± 0.92 and 3.14 ± 1.42 MJ/d, respectively) for the group of women, but were more variable on an individual basis. Results of this long-term energy balance study suggest that the RDAs underestimate the dietary energy requirement of older women.

THE RECOMMENDED Dietary Allowance (RDA) for energy of women and men aged 50 years and older is set at 1.5 × resting energy expenditure (REE).[1] This allowance is consistent with the one energy requirement study in noninstitutionalized older men[2] available to the 1989 RDA committee; no energy requirement studies of older women had been performed when this energy allowance was established. This energy allowance is lower than that for younger adults and reflects, in part, the effects of an age-associated decline in REE,[3] mainly due to sarcopenia,[4] and a reduced energy expenditure of physical activity (EEPA), due to a more sedentary life-style.[5,6]

More recently, a few energy requirement assessments of older women have been published using doubly labeled water techniques to measure total energy expenditure (TEE). These studies have produced conflicting results, with some reporting an energy requirement similar to the RDA[7-9] and another reporting a higher energy requirement.[10] Individual differences in REE and levels of physical activity may account, in part, for these conflicting results. These differences also may have been influenced by the way doubly labeled water data were analyzed, calculated, and interpreted,[11] especially as applied to elderly people.[12,13]

An individual's energy requirement is the energy intake necessary to balance energy expenditure, such that body weight and body composition consistent with good health are maintained over long periods. For a person in energy balance, energy intake equals energy expenditure. The most accurate way to determine an energy requirement from energy intake is via a long-term intake-balance study.[14] To date, no such study has been performed in older women.

Thus, the purpose of this study was to determine the energy requirement of healthy, free-living older women by measuring the total energy intake (TEI) required to maintain body weight during a 14-week intake-balance period. In addition, the need exists to be able to accurately and conveniently assess patterns and levels of physical activity in older persons. To this end, comparisons were made between the EEPA derived from the intake-balance study and estimated from the Yale Physical Activity Survey (YPAS),[15] an interviewer-administered questionnaire specifically designed to assess physical activity of older people.

SUBJECTS AND METHODS

Subjects

Nine women aged 56 to 78 years volunteered for this 14-week intake-balance study after responding to advertisements placed in a local newspaper. Before acceptance into the study, each woman completed an evaluation that included a medical history, a physician-administered physical examination, a resting electrocardiogram, and routine blood and urine chemistries. After receiving complete written and verbal explanations of the study, each woman signed an informed-consent agreement. The study protocol and informed-consent agreement were reviewed and approved by the Institutional Review Board, The Pennsylvania State University, University Park, PA, and the Clinical Investigation Committee, The Pennsylvania State University, The Milton S. Hershey Medical Center, Hershey, PA.

Experimental Design

The 14-week intake-balance study was conducted at a General Clinical Research Center (GCRC) located at the Noll Physiological Research Center on the University Park campus of The Pennsylvania State University. Each woman maintained her customary life-style while living at home during 10 of 14 study weeks. During study weeks 2, 3, 8, and 14, each woman lived at the GCRC but was encouraged to maintain her habitual level of daily activity as much as possible. These weeks corresponded with the testing and evaluation periods for the study. The women were allowed to leave the GCRC during the residency periods. The only restrictions placed on the women during residency were that they eat all of their meals at the GCRC, sleep at the GCRC, and be available for all testing and procedures.

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Address reprint requests to Wayne W. Campbell, PhD, Nutrition, Metabolism and Exercise Program, Center on Aging, University of Arkansas for Medical Sciences, 4301 W Markham, Slot 748, Little Rock, AR 72205-7199.

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Diet

All meals were prepared and provided by the Metabolic Research Kitchen at the GCRC. During the 10 free-living weeks, each woman consumed breakfast at the GCRC, but weekday lunches and dinners and all weekend meals were packed out. During the 4 weeks of residence, each woman consumed all of her meals at the GCRC.

The diet consisted of a rotating cycle of three daily menus of lacto-ovovegetarian foods portioned to provide 0.8 g protein $\cdot$ $kg^{-1} \cdot d^{-1}$ and sufficient dietary energy to maintain body weight (Table 1). Meats, foods that contain large quantities of protein, were omitted from the menus to allow a greater variety of protein-containing foods to be provided while maintaining the defined protein intake. Meats were also omitted from the menus to exclude an exogenous source of 3-methylhistidine, a compound measured in urine as an index of actomyosin breakdown. The nonprotein portion of each of the three menus was composed of 60% of energy from carbohydrate and 40% of energy from fat. The women were instructed to consume all of the food and beverages provided. To this end, the women were also instructed to scrape and rinse all of their dishes, glasses, and utensils with water and to consume the rinse water. Water, decaffeinated coffee, and decaffeinated tea were allowed ad libitum, and each woman consumed one multivitamin-multimineral supplement tablet daily throughout the study (Advanced Formula Centrum; Lederle Laboratories, Pearl River, NY).

The TEI of each woman was initially set based on the Harris-Benedict[16] equation of REE for women plus an EEPA allowance of 0.7 times this predicted REE. Use of the Harris-Benedict equation to accurately predict REE of older women has recently been reaffirmed.[17] The accuracy of the REE prediction was confirmed within the first 3 study days by directly measuring each woman's REE using an indirect calorimeter (described later). Adjustments to TEI were made as necessary during nonresidency periods throughout the study to maintain body weight within ±0.5 kg of the woman's mean body weight during study days 4 to 15. Any necessary adjustment of TEI was accomplished by either adding or subtracting low-protein foods and beverages from the woman's daily menu while maintaining the nonprotein carbohydrate to fat ratio at 60% to 40%. All women were body weight–stable at the TEI provided during the last 2 weeks of the study. For presentation, this TEI is designated as "TEI at week 14." TEI was calculated using Nutritionist IV software (version 4.0; N-Squared Computing, First Data Bank, San Bruno, CA) assuming the classic Atwater values of 16.7, 16.7, and 37.7 kJ/g metabolizable energy for protein, carbohydrate, and fat, respectively.

REE Measurements

REE was measured in the fasting state one morning at the end of study week 14. Each woman was escorted from her residence room at

Table 1. Composition and Macronutrient Content of a Representative 3-Day Cycle Menu

Meal	Menu 1	(g/d)	Menu 2	(g/d)	Menu 3	(g/d)
Breakfast	Orange juice	150	Orange juice	120	Orange juice	120
	Whole milk	180	Whole milk	180	Whole milk	180
	Scrambled egg	50	Oat cereal	30	Blueberry muffin	40
	Wheat toast	38	English muffin	52	Chocolate/ peanut-butter bar	36
	Oat bran cereal	28	Margarine	9	Margarine	9
	Margarine	9	Decaffeinated coffee/tea	(optional)	Decaffeinated coffee/tea	(optional)
	Decaffeinated coffee/tea	(optional)				
Lunch	Cheddar cheese	60	Wheat bread	76	Lettuce	130
	Wheat crackers	60	Peanut butter	32	Hard-boiled egg	50
	Lettuce	50	Grape jelly	36	Swiss cheese	15
	Cooked egg white	10	Lettuce	50	Tomato	30
	Carrot sticks	60	Soy oil	16	Green pepper	12
	Soy oil	15	Vinegar	15	Carrots	15
	Vinegar	10	Peach slices	100	Soy oil	12
	Pear halves	100	Cranberry juice	250	Vinegar	15
	Cranberry juice	220			Pita bread	57
					Pineapple chunks	200
Dinner	Spaghetti	100	Vegetarian chili	1 U*	Broccoli rice casserole	1 U†
	Tomato sauce	115	Green beans	125	Italian bread	30
	Italian bread	30	Margarine	9	Low-protein cookie	28
	Margarine	4.5	Whole milk	180	Lemon pudding	150
	Applesauce	110	Cranberry juice	30	Nondairy whipped topping	20
	Cranberry juice	90			Whole milk	120
Group dietary intake‡						
Energy (MJ/d)§	9.05 ± 1.62		9.05 ± 1.59		9.03 ± 1.56	
Protein (g/d)	47.1 ± 7.3		44.7 ± 7.1		47.5 ± 7.6	
Carbohydrate (g/d)	296.5 ± 55.2		299.3 ± 54.3		293.6 ± 52.1	
Fat (g/d)	87.6 ± 16.1		87.5 ± 16.2		87.9 ± 16.1	

*Ingredients in 1 U vegetarian chili were 100 g mashed kidney beans, 95.6 g whole kidney beans, 31.2 g frozen corn, 26.1 g chopped green peppers, 16.9 g chopped onions, 8.6 g tomato paste, 8.1 g corn oil, 1.25 g salt, 0.38 g oregano, 0.30 g chili powder, 0.15 g garlic powder, 0.13 g cumin, and 110.4 g tap water.

†Ingredients in 1 U broccoli rice casserole were 41.3 g cooked white rice, 37.5 g cream of broccoli soup, 35.6 g frozen broccoli, 28.1 g water chestnuts, 22.5 g shredded cheddar cheese, 13.3 g chopped celery, 6.5 g whole milk, 5 g chopped onion, and 1.8 g corn oil.

‡Values are the mean ± SD; N = 9.

§Calculations based on 16.7, 16.7, and 37.7 kJ/g metabolizable energy for protein, carbohydrate, and fat, respectively.

the GCRC to the indirect calorimeter room and rested in a semirecumbent position for about 20 minutes. A clear plastic box, part of a ventilated-hood system, was then placed over her head while she rested supine for another 15 minutes. Then, the rates of oxygen consumption and carbon dioxide production (liters per minute for both) were measured and averaged from 15 consecutive 1-minute expired-air samples. REE was calculated by multiplying the oxygen consumption rate in liters per minute by the oxygen in kilojoules per liter associated with the respiratory exchange ratio of the expired air.[18]

The 1989 RDAs[1] use the terms "basal metabolic rate" (BMR) and "REE" interchangeably. However, "BMR is more precisely defined as the REE measured soon after awakening in the morning, at least 12 hours after the last meal."[1] In contrast, REE may not be measured under basal conditions and may "include the residual thermic effect of a previous meal and may be lower than BMR during quiet sleep."[1] The present REE data were obtained using highly controlled and appropriate experimental conditions consistent with BMR. However, the term REE is used to conform to the 1989 RDA nomenclature and to be consistent with other referenced publications where the conditions under which REE data obtained were not always clearly described.

Body Composition Measurements

Fasting body weight was measured to the nearest 0.1 kg each weekday of the 14-week study (model 2181; Toledo Scale, Toledo, OH; calibrated by standard dead-weight testing) with the women wearing underwear and a robe. Nude body weight was calculated as total body weight minus robe weight. Body height (without shoes) was measured to the nearest 0.1 cm with a wall-mounted stadiometer one morning during week 1, and was assumed to remain constant throughout the study. Body mass index was calculated as weight in kilograms divided by height in meters squared.

Body density was measured by hydrostatic weighing[19] at week 2 and week 14. Lung residual volume was measured during the underwater procedure by nitrogen dilution.[20] Percent body fat was calculated from body density using the two-compartment model equation of Siri.[21] Body density measurements were not obtained for one woman, due to her uneasiness with the procedure.

Physical Activity Questionnaire

The YPAS,[15] an interviewer-administered questionnaire developed to assess habitual physical activity of older women and men, was completed at study weeks 2, 8, and 14. The questionnaire was administered by the same interviewer during private sessions with each woman. Results of the survey are reported as the total time (hours per week) and energy expenditure (kilocalories per week) for work, exercise, and recreational activity during a typical week in the past month and a categorical listing of different types of activity (ie, vigorous activity, leisurely walking, moving, standing, and sitting). The value reported for each activity category was derived by multiplying the frequency and duration of each activity and a weighting factor as detailed previously,[15] and was also compiled as the sum of each of the five categories of activity. For the purpose of data presentation, energy expenditure data were converted from kilocalories per week to megajoules per day using the factor, 1 kcal = 4.184 kJ.

Statistical Methods

Values are reported as the mean ± SD. Differences between measured and predicted group mean values were analyzed using Student's paired t test. The degree of linear association between variables was established using the Pearson product-moment correlation. Repeated-measures ANOVA was used to assess YPAS data collected at study weeks 2, 8, and 14. Results of the analyses were considered statistically significant at P less than .05 (two-sided). All data processing and statistical evaluations were performed using Microsoft Excel 5.0 (Microsoft, Redmond, WA) and Microsoft Excel Analysis ToolPak (GreyMatter International, Cambridge, MA).

RESULTS

Descriptive characteristics of the women studied and the energy intake and expenditure data for study week 14 are reported in Table 2. For long-term energy balance and body weight maintenance, TEI must match TEE. This was achieved for all of the women studied, as demonstrated by no significant change in body weight or percent body fat from baseline to study week 14. In addition, REE was similar at baseline and week 14. The TEI/REE ratio of 1.82 ± 0.15 is significantly greater ($P < .001$) than the TEE/REE ratio of 1.50 established by the 1985 Consultation[22] and recognized by the 1989 RDAs.[1] Use of the 1985 Consultation equation to predict REE from body weight (pREE) resulted in a TEI/pREE ratio of 1.73 ± 0.18, which is 5% less than TEI/REE but not statistically different. The 1.73 ratio remained significantly greater ($P < .005$) than a TEE/REE ratio of 1.50.

TEI may be divided into components of energy expenditure that include the REE, the thermic effect of feeding (TEF), and the EEPA. The TEF is calculated and assumed to be equal to 10% of TEI.[1] The EEPA is calculated as TEI minus the sum of REE and TEF. For these older women, REE and EEPA accounted for 55% and 35% of TEI, respectively.

Repeated-measures ANOVA of data for total time of activity

Table 2. Subject Characteristics and Energy Intake and Expenditure During Long-Term Body Weight Maintenance in Older Women (N = 9)

Variable	Mean ± SD	Range
Age (yr)	67 ± 9	56-78
Body mass index (kg/m²)	22.9 ± 3.1	17.0-28.2
Height (m)	1.60 ± 0.06	1.53-1.72
Weight (kg)		
Baseline	57.9 ± 9.3	40.8-71.5
Wk 14	58.0 ± 9.1	41.2-71.2
Body fat (%)*		
Baseline	36.6 ± 4.8	28.0-44.1
Wk 14	37.7 ± 4.3	29.0-42.5
TEI (MJ/d)†	9.03 ± 1.60	7.54-12.11
REE (MJ/d)‡		
Baseline	5.09 ± 0.53	4.59-5.97
Wk 14	4.94 ± 0.67	4.00-6.06
pREE wk 14 (MJ/d)	5.20 ± 0.57	4.29-6.06
TEI/REE	1.82 ± 0.15§	1.57-2.00
TEI/pREE	1.73 ± 0.18‖	1.52-2.03
TEI-REE (MJ/d)	4.09 ± 1.07	2.78-6.05
TEF (MJ/d)	0.90 ± 0.16	0.75-1.21
EEPA (MJ/d)	3.18 ± 0.92	2.01-4.84

Abbreviations: pREE, resting energy expenditure predicted from body weight[22]; TEF, thermia effect of feeding, calculated and assumed to equal TEI × 0.1; EEPA, energy expenditure of physical activity, equal to TEI − REE − TEF.

*Measured via hydrostatic weighing; N = 8.

†TEI for body weight maintenance at the last week of the 14-week intake-balance period.

‡Measured via indirect calorimetry. Measurements were made in the early morning soon after each woman had awakened, and in the postabsorptive state.

§$P < .001$, ‖$P < .005$: significantly different from 1.50.

(hours per week) and energy expenditure (megajoules per day) from weeks 2, 8, and 14 did not establish a significant change over time, and the data were averaged to provide a mean estimate of physical activity during the 14-week intake-balance period (Table 3). The group mean EEPA-YPAS of 3.14 ± 1.42 $MJ \cdot d^{-1}$ is similar to the EEPA of 3.18 ± 0.92 $MJ \cdot d^{-1}$ derived from the intake-balance data (Table 4). The group means for EEPA and EEPA-YPAS were similar (a difference of 0.04 ± 0.65 MJ/d, 1.7% ± 21.7%) and a correlation of .938 ($P < .0002$) was established between EEPA and EEPA-YPAS, but there was great variability in individual results. For example, compared with EEPA, EEPA-YPAS was 36.8% lower in subject no. 7 and 17.0% higher in subject no. 5.

DISCUSSION

The 1985 FAO/WHO/UNU Consultation[22] defined the requirement for energy as "the level of energy intake from food that will balance energy expenditure when the individual has a body size and composition, and level of physical activity, consistent with long-term good health; and that will allow for the maintenance of economically necessary and socially desirable physical activity." This definition includes the understanding that for a given body weight and level of physical activity, energy balance is achieved at only one energy intake level. If energy intake does not balance energy expenditure over time, then body weight will change in association with changes in body energy stores, mainly adipose tissue stores. For the present study, body weight was maintained at ±0.5 kg baseline body weight and percent body fat did not change from baseline to week 14. Controlled underfeeding and overfeeding studies in older men have shown that a 1-kg body weight change will occur with either a 32.6-MJ (7,800-kcal) energy deficit or a 38.2-MJ (9,120-kcal) energy excess.[23] Assuming that older women respond similarly, a 418-kJ/d (100-kcal/d) energy imbalance would result in a 0.5-kg loss or gain of body weight by 39 and 46 days, respectively. Both of these periods are well within the 14-week (98-day) study period.

To maintain body weight stability within ±0.5 kg, TEI provided at baseline had to be adjusted for seven of nine women studied (increased for five women and decreased for two women). No more than three TEI adjustments were necessary for any woman. The mean time to the first TEI adjustment for these seven women was 29 ± 23 days (mean ± SD; range, 5 to 80; 20 ± 9 days excluding the one subject whose TEI was changed once at day 80), and the mean time to the final TEI adjustment was 58 ± 19 days (range, 22 to 80). Our experience suggests that daily monitoring of fasting body weight for a minimum of 3 weeks and possibly as long as 8 weeks is necessary (or desirable) if body weight is to be used as a criteria method to establish or assess energy balance. Studies claiming energy balance of subjects based on body weight stability of less than 3 weeks (and especially of ≤1 week) should be viewed with caution.

At present, the most accurate way to measure TEI is via the intake-balance method, and the most accurate way to measure TEE is via the doubly labeled water technique.[14,24] These two techniques have provided comparable estimates of energy requirements in young men.[14] Table 5 provides a summary of published energy requirement estimates in older women and men using either the intake-balance method or the doubly labeled water technique. Only one study in older men was published when the current national[1] and international[22] energy requirements were established. Calloway and Zanni[2] reported an energy requirement of 1.58 ± 0.07 × REE for six men aged 63 to 77 years during a 7-week intake-balance experiment. These men, described as healthy and ambulatory, were confined to a metabolic unit throughout the study and engaged in sedentary activity for most of the day, except for two required 15-minute sessions on a cycle ergometer at a heart rate less than 130 bpm. All diets consisted of liquid formula beverages that provided virtually no protein (study days 1 to 17) or inadequate protein (study days 18 to 47).[25] The investigators noted that without the required cycling exercise sessions, energy expenditure would have been approximately 418 kJ (100 kcal) lower and the energy requirement would have been 1.50 × REE. This energy requirement was described as a "nutritional floor, not necessarily an optimal intake target,"[2] a plausible description given the confined, sedentary life-style maintained by these men.

In support of the present long-term intake-balance study results, Reilly et al[10] reported an energy requirement of 1.80 ± 0.06 for 11 older women, and Roberts et al[12] reported an energy requirement of 1.75 ± 0.05 for 15 older men (Table 5). All of the women and men who participated in these three studies were described as healthy, free-living, and moderately active. To the extent that these general descriptors are not common for some older persons, these energy requirement estimates would overestimate the energy needs of the elderly population as a whole.

Other energy requirement estimates in older men and women were only marginally higher than or similar to the energy

Table 3. YPAS Results for Older Women During a 14-Week Energy Intake-Balance Study

YPAS	Week 2	Week 8	Week 14	Average
Activities checklist				
Total time (h/wk)	34.1 ± 17.1	26.7 ± 20.3	21.4 ± 17.1	27.4 ± 17.4
Energy expenditure (MJ/d)	3.96 ± 1.83	2.87 ± 1.52	2.57 ± 1.39	3.14 ± 1.42
Activity dimensions indices				
Vigorous (U/mo)	17.2 ± 20.9	15.0 ± 15.8	20.0 ± 15.8	17.4 ± 15.3
Leisurely walk (U/mo)	18.2 ± 15.8	16.0 ± 17.5	16.0 ± 17.4	16.0 ± 16.6
Moving (h/d)	11.3 ± 3.3	8.7 ± 2.8	8.4 ± 4.2	9.5 ± 2.9
Standing (h/d)	2.4 ± 0.9	2.4 ± 0.9	2.7 ± 1.0	2.5 ± 0.7
Sitting (h/d)	2.1 ± 0.6	2.3 ± 0.7	3.0 ± 2.8	2.5 ± 1.0
Summary (total U)	51.3 ± 21.5	44.4 ± 23.2	50.4 ± 23.3	48.7 ± 20.6

NOTE. Values are the mean ± SD; N = 9.

Table 4. A Comparison in Older Women Between EEPA Estimated From the YPAS and That Derived From a 14-Week Energy Intake-Balance Study

Subject No.	EEPA (MJ/d)*	EEPA-YPAS (MJ/d)	Difference MJ/d	%
1	4.40	5.14	0.74	16.8
2	2.79	2.14	−0.65	−23.3
3	2.66	2.06	−0.60	−22.6
4	3.37	3.82	0.45	13.4
5	2.41	2.82	0.41	17.0
6	4.84	5.32	0.48	9.9
7	2.01	1.27	−0.74	−36.8
8	2.98	2.10	−0.88	−29.5
9	3.20	3.56	0.36	11.3
Mean ± SD	3.18 ± 0.92	3.14 ± 1.42	−0.04 ± 0.65	1.7 ± 21.7

*EEPA at week 14 of an energy intake-balance study (equal to TEI − REE − TEF).

allowance of 1.50 × REE (Table 5).[7-9,26] Factors contributing to these lower energy requirement estimates may have included studying individuals with low levels of habitual EEPA[8] and conducting the study during winter months when the habitual EEPA of the subjects may have been lower than at other times of the year.[7] The present study was conducted from January 1995 to August 1996 with women participating during each of the four seasons. The energy requirement estimates reported by Goran and Poehlman[9] may have underestimated TEE by about 10% due to the use of a higher ratio of the dilution spaces (^2H_2O:$H_2^{18}O$) for the calculations as compared with other doubly labeled water studies.[13] Recently, Roberts[13] reported a mean TEE/REE ratio of 1.69 for both older women and men using measured REE and 1.71 for women and 1.77 for men using the 1985 WHO equation[22] to predict REE. These estimates were provided as part of a comprehensive review and summary of data from published doubly labeled water–derived energy requirement studies in older people. All of these values are higher than the recommended energy allowance of 1.50 × REE[22] and support the present results.

We are aware that use of the Atwater value of 16.7 kJ/g for carbohydrate may overestimate the actual metabolizable energy from carbohydrate, and thus total metabolizable energy, due to an overestimation of the energy value of unavailable carbohydrate in the diet. However, when unavailable carbohydrate is consumed at intakes typical of the diet in Western countries (<30 g unavailable carbohydrate/d), any bias introduced into the energy requirement estimate by using the Atwater equation is very small (≤1%)[27] and would certainly not explain the high energy needs of these older women. The unavailable carbohydrate provided in the present study was approximately 13 to 24 g/d, based on the total dietary fiber values provided in the Nutritionist IV computer program.

The YPAS[15] was developed in response to the need for a sensitive and accurate way to estimate physical activity patterns and EEPA of older people. Unlike other physical activity survey questionnaires, the YPAS was designed specifically for use with older people based on activities data obtained during interviews with older people. The close similarity between the mean EEPA estimated from the YPAS and derived from the intake-balance study (Table 4) and the highly significant association among individual subject's EEPA and EEPA-YPAS support the YPAS as an accurate and useful tool to assess physical activity in groups of older women. Similar observations have been made for other interviewer-administered physical activity questionnaires.[9,10] These findings for the YPAS are promising, yet should be considered preliminary given the small number of women studied. Also, the large within-subject variability between EEPA and EEPA-YPAS (Table 4) highlights the limitation of and the caution required to use the YPAS to predict the

Table 5. Energy Requirement Estimates in Older Women and Men (MJ/d)

Study	Subject Data No., Sex, Age (yr)	TEI*	TEE†	REE‡	
Intake-balance					TEI/REE
Present study	9, F, 67 ± 3	9.03 ± 0.53	—	4.97 ± 0.22	1.82 ± 0.05§
Calloway and Zanni, 1980[2]	6, M, 68 ± 2	10.96 ± 0.38	—	6.79 ± 0.32	1.58 ± 0.03§
Doubly labeled water					TEE/REE
Reilly et al, 1993[10]	10, F, 73 ± 1	—	9.21 ± 0.47	5.11 ± 0.12	1.80 ± 0.06§
Sawaya et al, 1995[8]	10, F, 74 ± 1	—	7.59 ± 0.28	4.79 ± 0.14	1.59 ± 0.06‖
Goran and Poehlman, 1992[9]	6, F, 64 ± 2	5.99 ± 0.70	8.75 ± 0.39	6.16 ± 0.22	1.43 ± 0.08
	7, M, 68 ± 2	9.73 ± 0.39	11.19 ± 0.62	7.18 ± 0.29	1.58 ± 0.11
	13 F and M combined	8.00 ± 0.65	10.07 ± 0.51	6.71 ± 0.23	1.51 ± 0.07
Pannemans and Westerterp,	10, F, 68 ± 1	—	—	—	1.66 ± 0.06¶
1993 and 1995[7,26]	16, M, 71 ± 1	—	—	—	1.52 ± 0.05¶
	26 F and M combined	8.77 ± 0.26#	9.60 ± 0.31	6.22 ± 0.20	1.58 ± 0.04¶
Roberts et al, 1992[12]	15, M, 69 ± 2	10.90 ± 0.29	10.44 ± 0.38	5.98 ± 0.17	1.75 ± 0.05

NOTE. Values are the mean ± SEM.
Abbreviations: M, male; F, female.
*TEI for body weight maintenance.
†TEE measured using the doubly labeled water technique.
‡REE measured during the early morning in a fasting state using indirect calorimetry techniques.
§$P < .05$, ‖$P = .055$: significantly different from TEE/REE = 1.50
¶Statistical significance undetermined.
#Subjects were in negative energy balance during 2-week study period and lost significant body mass.

EEPA of an individual older woman. Further validation with larger numbers of subjects and possible use of the doubly labeled water technique to measure TEE would be helpful.

Results of the YPAS from study weeks 2, 8, and 14 were similar and were averaged to represent the physical activity patterns throughout the intake-balance period (Table 3). Although not statistically significant over time, possibly due to the small sample size (N = 9), the mean values for total time ($P = .348$) and energy expenditure ($P = .172$) trend progressively lower at weeks 8 and 14 compared with week 2. When compared directly using a paired t test, total time and energy expenditure at baseline are significantly higher than the respective values at week 14 ($P < .01$). This pattern is consistent with the lower mean total time ($P = .05$) and the mean energy expenditure ($P = .06$) values reported for the second administration of the YPAS for a 2-week repeatability assessment.[15] These trends may reflect the women's overestimating their level of physical activity for the first questionnaire and becoming more attentive to their activities for subsequent questionnaires. Researchers or clinicians using the YPAS may consider familiarizing subjects with the questionnaire before conducting the interview or administering the interview twice at the start of a research study to help control for this possibility. These trends may also reflect changes in habitual activity patterns while participating in the 14-week intake-balance study (eg, not shopping for, preparing, or cleaning up after meals) or eating and sleeping at the GCRC during the weeks of residence. The seasonal adjustment score correction available with the YPAS was not used for the present data, because each of the three questionnaires for a given woman was administered within a 3-month period.

A consensus on the energy requirement of older women, based on previously published data and the present study data, is not yet possible. These long-term intake-balance data indicate that the dietary energy needs of older women are significantly greater than the current RDA for energy. These results emphasize that healthy, moderately active older people consume and expend more energy than previously thought, but should not be interpreted as a recommendation for older people with appropriate and stable body weights to increase energy intake.

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REFERENCES

1. National Research Council: *Recommended Dietary Allowances* (ed 10). Washington, DC, National Academy Press, 1989

2. Calloway DH, Zanni E: Energy requirements and energy expenditure of elderly men. Am J Clin Nutr 33:2088-2092, 1980

3. Tzankoff SP, Norris AH: Longitudinal changes in basal metabolic rate in man. J Appl Physiol 33:536-539, 1978

4. Evans WJ, Campbell WW: Sarcopenia and age-related changes in body composition and functional capacity. J Nutr 123:465-468, 1993

5. McGandy RB, Barrows CH, Spanias A, et al: Nutrient intake and energy expenditure in men of different ages. J Gerontol 21:581-587, 1966

6. Vaughan L, Zurlo F, Ravussin E: Aging and energy expenditure. Am J Clin Nutr 53:821-825, 1991

7. Pannemans DLE, Westerterp KR: Energy expenditure, physical activity and basal metabolic rate of elderly subjects. Br J Nutr 73:571-581, 1995

8. Sawaya AL, Saltzman E, Fuss P, et al: Dietary energy requirements of young and older women determined by using the doubly labeled water method. Am J Clin Nutr 62:338-344, 1995

9. Goran ML, Poehlman ET: Total energy expenditure and energy requirements in healthy elderly persons. Metabolism 41:744-753, 1992

10. Reilly JJ, Lord A, Bunker VW, et al: Energy balance in healthy elderly women. Br J Nutr 69:21-27, 1993

11. Roberts SB, Dietz W, Sharp T, et al: Multiple laboratory comparison of the doubly labeled water method. Obes Res 3:3-14, 1995 (suppl)

12. Roberts SB, Young VR, Fuss P, et al: What are the dietary energy needs of elderly adults? Int J Obes 16:969-976, 1992

13. Roberts SB: Energy requirements of older individuals. Eur J Clin Nutr 50:S112-S118, 1996 (suppl)

14. Seale JL, Rumpler WV, Conway JM, et al: Comparison of doubly labeled water, intake-balance, and direct- and indirect-calorimetry methods for measuring energy expenditure in adult men. Am J Clin Nutr 52:66-71, 1990

15. DiPietro L, Caspesen CJ, Ostfeld AM, et al: A survey for assessing physical activity among older adults. Med Sci Sports Exerc 25:628-642, 1993

16. Harris JA, Benedict FG: *A Biometric Study of Basal Metabolism in Man.* Washington, DC, Carnegie Institute of Washington, 1919

17. Taaffe DR, Thompson J, Butterfield G, et al: Accuracy of equations to predict basal metabolic rate in older women. J Am Diet Assoc 95:1387-1392, 1995

18. McArdle WD, Katch FL, Katch VL: *Exercise Physiology. Energy, Nutrition, and Human Performance* (ed 3). Philadelphia, PA, Lea & Febiger, 1991

19. Akers R, Buskirk ER: An underwater weighing system utilizing "force cube" transducers. J Appl Physiol 26:649-652, 1969

20. Wilmore JH: A simplified method for determination of residual lung volumes. J Appl Physiol 27:96-100, 1969

21. Siri WE: Body composition from fluid spaces and density: Analysis of methods, in *Techniques for Measuring Body Composition.* Washington, DC, National Academy of Sciences, 1961, pp 223-244

22. FAO/WHO/UNU: *Energy and Protein Requirements.* Geneva, Switzerland, WHO, 1985

23. Roberts SB, Fuss P, Heyman MB, et al: Control of food intake in older men. JAMA 272:1601-1606, 1994

24. Mertz W, Tsui JC, Judd JT, et al: What are people really eating? The relation between energy intake derived from estimated diet records and intake determined to maintain body weight. Am J Clin Nutr 54:291-295, 1991

25. Zanni E, Calloway D, Zezulka A: Protein requirements of elderly men. J Nutr 109:513-524, 1979

26. Pannemans DLE, Westerterp KR: Estimation of energy intake to feed subjects at energy balance as verified with doubly labelled water: A study in the elderly. Eur J Clin Nutr 47:490-496, 1993

27. Livesey G: Energy values of unavailable carbohydrate and diets: An inquiry and analysis. Am J Clin Nutr 51:617-637, 1990