Canadian Recommended Nutrient Intakes Underestimate True Energy Requirements in Middle-aged Women

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ABSTRACT

To examine whether Health Canada's Recommended Nutrient Intakes (RNI) and FAO/WHO/UNU (Food and Agriculture Organization, World Health Organization, United Nations University) values provide accurate indices of true energy requirements, energy expenditure was determined using doubly labelled water (DLW) over 13 days in a group of 29 middle-aged women. Energy intakes were calculated from weighed food intake, and energy expenditures and intakes were then compared with individual calculated RNI requirements. The mean energy requirement as determined by DLW expenditure (9.56 ± 0.53 MJ/d) was higher ($p<0.0001$) than reported energy intake (7.08 ± 0.30 MJ/d) and was higher ($p<0.004$) than RNI mean energy requirement (7.97± 0.18 MJ/d). The mean RNI for energy was also lower ($p<0.0001$) than that derived from FAO data. These results suggest that current Health Canada RNIs are inadequate in predicting the energy needs of Canadian middle-aged women.

ABRÉGÉ

Il apparait de plus en plus évident que les méthodes factuelles servant à déterminer les besoins énergétiques aient tendance à sous-estimer les besoins réels. Afin d'évaluer si l'apport nutritionnel recommandé (ANR) de Santé Canada ainsi que les données de FAO/OMS/UNU correspondent aux besoins énergétiques réels, les dépenses énergétiques d'un groupe de 29 femmes de 37 à 57 ans furent déterminées sur une période de 13 jours utilisant de l'eau doublement marquée. Les apports en énergie furent parallèlement calculés à l'aide de nourriture pesée. Les dépenses et besoins énergétiques furent comparés aux besoins calculés. La moyenne des besoins en énergie déterminée par dépenses énergétiques (9,56 ± 0,53 MJ/j) était plus grande ($p<0,001$) que celle rapportée (7,08 ± 0,30 MJ/j). Les besoins en énergie déterminés par l'eau doublement marquée furent significativement plus élevés ($p<0,004$) que l'ANR par Santé Canada (7,97 ± 0,18 MJ/j). De plus, les ANR de Santé Canada furent significativement plus bas ($p<0,0001$) que ceux obtenus à l'aide des données de la FAO. Ces résultats suggèrent que les ANR présentement établis par Santé Canada s'avèrent inadéquats en ce qui a trait à l'établissement des besoins en énergie de femmes canadiennes.

There is little dispute that body weight extremes result in increased health risk. Excess body weight is associated with higher risk of heart disease, type II diabetes, hypertension and certain forms of cancer,[1-4] while low body mass indices (BMI) are linked to increased mortality[5] and morbidity.[6] This J-shaped BMI-related mortality curve emphasizes the importance of maintaining energy balance in the Canadian population. Of central concern in addressing the problems of energy imbalance is knowing the exact energy requirements of any population subgroup. This is important for both private and public sector institutions catering to human feeding, permitting food systems' management teams to adequately nourish the institutionalized. Institutions providing food to active, healthy subjects should be able to confidently use the present Health Canada Recommended Nutrient Intakes (RNIs) for energy to plan and provide diets consistent with good health.[7,8] The accuracy of energy RNIs is also crucial in establishing welfare allowances and poverty lines in the less affluent.

Present values for population energy requirements are based largely on two methodologies. The first method, a "factual" technique, considers reported energy intake in a representative sample of the population as an index of energy requirement. Factual techniques use nutrient intake assessment instruments, including food frequency questionnaires, food records and 24-hour food recalls. Such approaches assume that during the period of measurement body energy mass is conserved; therefore energy intake equals expenditure, thus requirement. This factual approach largely forms the basis for the Health Canada energy requirement values.[8]

A second means of determining the energy requirements of a population is theoretical, or "factorial", based on assessment and summation of individual components of total energy requirement. In the factorial approach, the composite contributions of the energy required for basal metabolic rate, the thermic effect of food and activity are summed. Basal energy requirements are based on literature norms corrected for age and body weight. Energy needs for activities other than basal metabolic rate are assessed as an average multiple of this value and added to it to provide total energy expenditure. Using the factorial system, summed energy costs, thus requirements, have been determined for individuals with light, moderate and heavy occupational work loads,[7,8] as reported by FAO/WHO/UNU (Food and Agriculture Organization, World Health Organization, United Nations University).

Despite the importance of a reliable definition of energy requirements, accumulating evidence suggests that Canadian RNIs for energy may be in error for some population subgroups. Distinct weaknesses have been reported in the ability of factual and factorial techniques to accurately determine energy needs of groups of individuals.[9-14] Findings from such studies suggest that energy needs of subgroups of

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Canadians have likely been previously underestimated. Fortunately, a method for measuring energy needs has been more recently developed that provides an integrative, noninvasive and accurate assessment of energy expenditure over longer periods. For individuals at energy balance, energy requirement can be taken as identical to energy expenditure. The technique, doubly labelled water (DLW), uses the difference between elimination rates of oxygen and hydrogen from the body, measured using oxygen-18 (^{18}O) and deuterium (D) respectively, to calculate the rate of carbon dioxide expired. The method relies on the principle that elimination of oxygen occurs both as water and carbon dioxide, while that of hydrogen occurs only as water. DLW has been shown to be accurate to 2 to 3% and precise to 3 to 5% against other reputable techniques.[15-20]

The goal of the present analysis was to re-examine energy requirements in a group of middle-aged Canadian women using the DLW method. In this study, we tested the hypothesis that the measured energy requirements of middle-aged women are consistent with those indicated by present Canadian RNIs and the WHO/UNU/FAO guidelines.

METHODS

Subjects

The women recruited were part of an ongoing Canadian Diet and Breast Cancer Prevention Trial, and were selected for their increased risk of breast cancer according to the presence of extensive mammographic densities (>50% of the breast volume occupied by mammographic densities). Trial participants were randomly assigned to a low fat dietary intervention group (mean of 21% energy from fat) or the usual diet control group (mean of 32% energy from fat). The procedures of the trial have been previously described.[21,22]

All subjects were nondiabetic, not pregnant or lactating and reportedly had not gained or lost more than 4.5 kg over the previous six months. Subjects also reported consistent physical activity patterns and consumption of no more than two alcoholic drinks per day. None reported taking diuretics or thyroid medications at the time of the study.

Written informed consent was obtained at the first clinic visit for the DLW study. The project was approved by the University of Toronto Review Committee on the Use of Human Subjects.

Measurement of energy intakes

Each subject recorded all food and beverages consumed for seven consecutive days over the first week of the DLW study period. Subjects were provided with a weigh scale and record book at the beginning of the week and instructed by a dietitian to record the exact quantity of all foods and beverages by weight or using household measures. Brand names of food products, methods of food preparation and ingredients or recipes of mixed dishes were recorded where possible.

Food records were analyzed using the Minnesota Nutrient Data System (NDS) software developed by the Nutritional Coordination Center, University of Minnesota. Analysis of all subjects' records was performed by the same dietitian.

Doubly labelled water procedure for measuring total energy requirement

Total energy expenditure was measured over 13 days. Subjects were instructed to maintain their normal daily activities and eating patterns and to make no conscious attempt to lose or gain weight during the study period.

On day 0 of the study, fasting subjects were weighed to the nearest 0.1 kg; they then provided baseline urine and saliva samples. A single dose of 0.07 g/kg weight of D_20 (99.8 APE, Isotec, Miamisburg, OH) and 0.17 g/kg body weight of $H_2^{18}O$ (30 atom percent excess [APE], Advanced Material and Technology, New York, NY) was given orally followed by 100 mL of unlabelled tap water. This dosage corresponded to 0.35 g of $H_2^{18}0$ per kg of total body water. Total body water was estimated before the start of the study from skinfold thickness measures (triceps, suprailiac and subscapular) taken during participation in the dietary intervention trial and using the regression equations of Durnin and Womersley.[23]

Subjects consumed no food or fluids for four hours after the isotope dosing. Saliva samples were collected at three and four hours after the dose for measurement of total body water from deuterium isotope dilution. A urine sample was collected by each subject on the morning of day 1, 24 hours after isotope administration. On the morning of day 14, subjects returned to the clinic in a fasted state, and a urine sample was obtained. Day 1 and day 14 urine samples were used to measure elimination rates of deuterium and $^{18}0$. A further dose of labelled water (0.07 g/kg body weight of D_2O) was then administered and the subjects fasted for four hours. Saliva samples were collected at three and four hours after the dose for the determination of final total body water. All samples were stored frozen at -5° C in airtight parafilm-wrapped plastic containers and transported to the analytical facility on dry ice for isotopic analysis.

DLW laboratory analyses and calculations

Samples were prepared for isotopic analysis using standard vacuum techniques as previously described.[15] Isotopic measurements for deuterium and ^{18}O were carried out with a VG Isogas 903D dual-inlet isotope ratio mass spectrometer (Vacuum Generators, Cheshire, U.K.) with electrical H^{3+} compensation using conventional reference standards.

Carbon dioxide production was calculated according to the following equation:[20]

$$\mathbf{rCO_2 = 0.46TBW(1.01k_o - 1.04k_d)} \quad \textbf{Eqn 1}$$

where rCO_2 is the rate of carbon dioxide production (mol/d), TBW (mol) is the average of total body water measured on day 0 and day 14, and k_d and k_o are the calculated elimination rates (per day) of D and ^{18}O respectively. Total body water was determined from isotope dilution space of deuterium divided by 1.04.

Total energy expenditure was calculated from the CO_2 production rates using the formula of indirect calorimetry of de Weir.[24] Subjects' respiratory quotients were estimated using food quotients[25] derived from the seven consecutive day food records maintained during the study period. Errors in respiratory quotients obtained indirectly through food quotients were found, on calculation, to produce only a small inaccuracy with regard to DLW estimations of energy expenditure.

TABLE I
Selected Characteristics of the Group Under Study

Characteristic	Mean (SEM) (n=29)
Age (yr)	48.7 ± 0.9
Weight (kg)	61.9 ± 1.2
BMI (kg/m^2)	23.3 ± 0.5
Reported energy intake (MJ/d)	7.0 ± 0.3
Reported fat intake (%)	24.0 ± 1.2
Activity category (XBMR)*	1.4 ± 0.1

* Average multiple of BMR based on total hours spent in activities of moderate, hard and very hard intensity, calculated from the physical diary maintained during the 2 week study period.

TABLE II
Isotopic Data, Carbon Dioxide Production and Respiratory Quotients (n=29)

Variable	Mean	SD	Range
Elimination rates of ^{18}O (pool/day)	0.12	0.02	0.08-0.20
Elimination rates of deuterium isotopes (pool/day)	0.09	0.05	0.06-0.17
Average deuterium dilution space (kg)	31.63	4.60	24.92-44.36
Carbon dioxide production (mole/d)	18.05	5.56	8.33-37.93
Respiratory quotient*	0.88	0.02	0.83-0.92

* Calculated from food quotients obtained from food records during the first 7 days of the DLW study period.

TABLE III
Inherent Assumptions in Determination of Human Energy Intakes/Requirements Using Factual Approaches

(i) The method or instrument for recording food intake is accurate such that individuals do not forget or deliberately omit reporting of food items.

(ii) Individuals do not vary typical food intake profiles during the surveillance period; this assumption differs across food intake instruments affecting 24 h recall most and food frequency analyses least.

(iii) Appropriate analytical methods are used to measure the nutrient composition of the foods reported.

(iv) Descriptions of food items and/or source of nutrient values in food composition tables are accurate.

(v) The nutrient composition of foods does not vary according to factors such as genetics, environment, food preparation or processing.

Calculation of energy needs

Values for energy requirements as specified in Health Canada's RNIs[8] were obtained using requirement data per kg of body weight multiplied by individual subjects' weights. For values obtained according to the FAO/WHO/UNU guidelines a similar approach was used. The activity category was determined from a physical activity diary maintained over the 13 days of energy expenditure measurement in a manner similar to that used in establishing the FAO requirements. Activity level was expressed as a multiple of basal metabolic rate (MET value). Activities were classified as light, moderate, hard or very hard and assigned a MET value based on the recommendations of Wilson et al.[26] The average MET value over 24 hours was calculated according to the time spent in each activity classification.

Statistical analysis

The data, presented as mean ± standard error of the mean (SEM) (except standard devision [SD] for Table II), were analyzed with the SAS statistical package (SAS Institute, Cary, NC). Measured energy requirements were compared by means of paired Student's t-tests with those obtained from reported energy intakes, and values derived from Health Canada RNIs and FAO/WHO/UNU guidelines. Differences were considered significant at the $p<0.05$ level.

RESULTS

Subject demographics

The demographic features of the study group are shown in Table I. The mean age of the 29 subjects was 48.7 ± 5.0 years (range of 37-57). Sixteen women were premenopausal, 11 were postmenopausal, and the remaining 2 were considered perimenopausal. Most subjects (86%) had occupations associated with light activity levels, and the remainder were considered to be at a light to moderate level of activity.

Isotopic data for the calculation of energy expenditure

A summary of the isotopic data, calculated carbon dioxide production and respiratory quotient data are presented in Table II.

One subject (#14) had a relatively high value for K_o (0.1627) and for deuterium dilution space (36.28 kg) resulting in an atypically elevated energy expenditure value of 19.9 MJ/d. When repeat isotopic analyses were conducted on samples from this subject, the same energy expenditure value was obtained. This level of energy expenditure corresponded to an energy requirement of 0.30 MJ/kg of body weight, whereas the mean energy requirement was 0.15 ± 0.03 MJ/kg (range of 0.09 to 0.21) for the other 28 subjects. Inclusion of this individual's energy requirement value in the data set was based on agreement between repeat analyses.

Comparison of subjects' energy expenditure values with their energy intakes and with the requirement levels calculated from the Health Canada RNIs and FAO/UNU/WHO guidelines are shown in Figure 1. The mean multiple of basal metabolic rate for the 29 subjects was 1.44 ± 0.07, indicating light activity in these women. Mean energy requirement determined by expenditure (9.56 ± 0.53 MJ/d) was significantly ($p<0.0001$) higher than reported intake (7.08 ± 0.30 MJ/d). Energy requirements determined by DLW were significantly higher than energy requirements obtained using Health Canada RNIs (7.97 ± 0.18 MJ/d)($p<0.004$). There was no difference in mean energy requirement determined by DLW compared with that obtained using FAO/UNU/WHO data (8.93 ± 0.07 MJ/d)($p=0.37$). Health Canada RNIs were also found to be significantly lower ($p<0.0001$) than those derived from FAO data. Exclusion of subject #14 from the data set did not significantly alter the findings of the comparison with either the Canadian RNIs ($p<0.002$) or FAO/UNU/WHO values (p = 78).

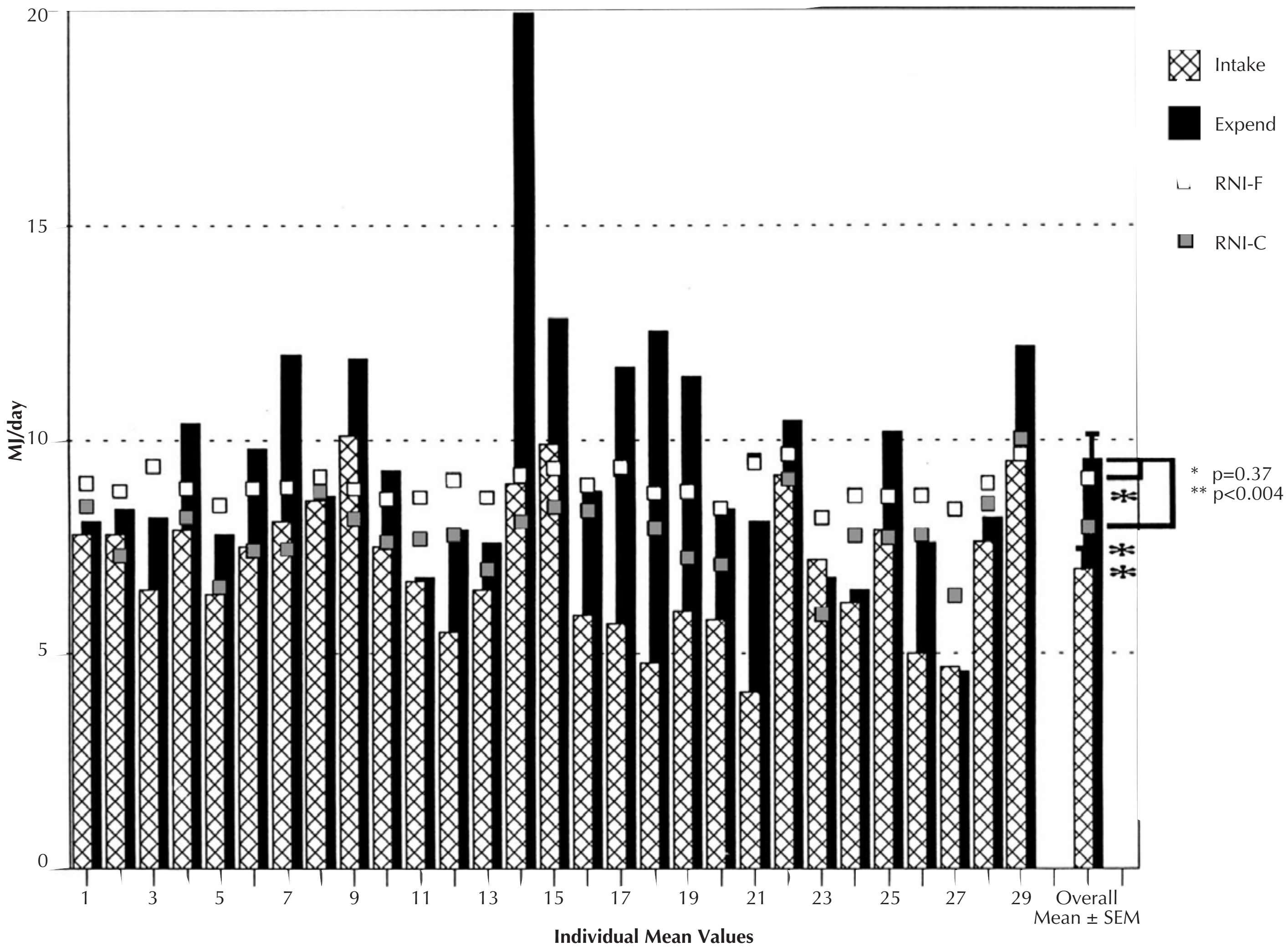

Figure 1. Comparison of individual values for energy expenditure determined using DLW (solid bars) and energy intake obtained using dietary records (hatched bars) with energy requirements as assessed using the Canadian RNIs (RNI-C) (dotted squares) and FAO/UNU/WHO (RNI-F) (white squares) standard values in the 29 subjects tested. Statistical analyses were performed with and without inclusion of subject #14.

DISCUSSION

For this subgroup of the Canadian population, factual and theoretical energy requirements have been previously compared. The average energy requirements of Canadian women as derived from factual data based on reported food intake were consistently lower than those obtained according to the factorial approach,[7] even when light activity was assumed. When moderate or higher levels of activity are considered, the difference between factual and theoretical methods becomes more marked. For example, for women aged 25 to 49 with heavy occupational activity levels, the energy requirements obtained using the current factual-based RNIs for Canadians (7.94 MJ/d) are 26% less than those derived from the factorial value (10.0 MJ/d). The present data using DLW suggest that the RNIs for energy in middle-aged women are substantially below the true requirement level of the population subgroup, while FAO/WHO/UNU values are more appropriate. In light both of possible limitations of factual and factorial methods, and the increasing awareness of the health benefits of exercise in the Canadian population, it is not unexpected that middle-aged women have higher determined energy requirements than predicted. Canadian RNIs for women over 75 years are 21% below levels prescribed for women in the age range in this study,[8] thus the same question needs to be addressed in the elderly.

Both food intake assessment and factorial methods possess significant limitations in measuring energy requirements. Food intake assessment methods rely on the assumptions given in Table III. Problems exist in both agreement among various methods of nutrient intake assessment, and in the ability of any available method to yield an accurate index of energy intake. For instance, a 34% underestimation of energy intake was obtained using 24 hour recall as compared with a self-reported weighed food intake,[9] although these recalls were made without the participation of interviewers who would have prompted subjects for food items that may have been omitted. Krantzler et al.[10] similarly showed that reported food intake using 3 and 7 day food records underestimated actual intake, assessed by observation, by 25 and 13% respectively. Such reports originally led to concerns about both the robustness of food intake evaluation instruments and the impact that perceived monitoring might have on subjects' eating habits.[27] Indeed, when energy intake was measured covertly in six men and one woman, average age 69 years, in a research environment, the reported mean values were 9.94 and 10.2 MJ/day during periods of sedentary and light activity, respectively.[28] These values are well in excess of current recommended levels of intake for energy.[7,8]

Theoretical methods are also subject to error in accurate definition of energy requirements. Basal energy metabolism based on anthropometric factors does not account for variations in the ratio of fat-free to fat tissue across individuals. Similarly, estimation of energy needs associated with activity are difficult to define with precision. Error arises in attempting to determine both the duration and precise energy costs of exercise subtypes. Indeed, the FAO/WHO/UNU 1985 report emphasizes that estimates of energy requirement should, when possible, be based on more direct measurements of expenditure, as was carried out in the present study.

The lack of reliability of food intake assessment has been confirmed by other studies that determined energy expenditure as measured by DLW and by self-reported dietary intake. The results have shown significant underreporting, particularly in overweight subjects.[29] Similarly, our own data[30] have shown in this group of middle-aged, normal-weight women that reported energy intakes were on average about 25% lower than values derived from determining energy expenditure by DLW. Consistent with these findings, other assessments of dietary intakes of Canadians have suggested intakes that are 5 to 15% lower than RNI values.[31,32] Thus, in whatever setting, energy requirements of individuals are better determined by approaches using energy expenditure, rather than energy intake. It has recently been claimed by Beaton that dietary intake data, whether obtained through records, recall or questionnaires, cannot be relied upon to provide an accurate quantitative measure of intake, although certain approaches are more accurate than others.[11,33] An unanswered question at present is whether one can predict the extent of underreporting of any given method and application in order to use with greater confidence the data obtained.

In the present work, energy intake was calculated using self-weighed food records kept on seven consecutive days by subjects who were carefully instructed in self-reporting procedures. Although the reported energy expenditure levels corresponded to those measured in other groups of women,[34,36] our subjects may not have been representative of typical Canadian middle-aged women in areas such as education, income, health behaviours and activity. The women examined in this study reported light activity, for instance. Despite these factors, it is evident that there is a need to study a larger sample of the population to accurately determine energy requirements. In this group of women, reported intakes were very close to Canadian RNI values, although actual expenditure levels were close to those established by the factorial method for moderately active women. Energy expenditure levels using DLW were considered accurate, as our laboratory has previously demonstrated good agreement between caloric requirement assessed by this technique and energy intake/balance in a group of competitive swimmers.[15] Moreover, the energy expenditure levels found in this study (mean = 9.56 MJ/d, n = 29) fell within the range of values reported for women of similar age and body profile obtained by others using DLW.[34-36] Derivation of energy expenditure values with DLW in this work relied on food quotients obtained from incomplete energy intake data. Although intake data were incomplete, it has been evaluated that even sizeable errors in food quotients translate into only minimal errors in energy production equations using DLW.

It should be noted that the comparison of DLW and Health Canada energy requirements in the present study was made on an individual basis, while the use of RNIs is more appropriate in predictive, population-based applications. As such, the RNI for energy provides a mean value for a population subgroup about which individual requirements are distributed. In a self-selection food distribution system typical of many institutions, it would be anticipated that, by use of accurate RNIs, individual requirements would also be satisfied given a normal distribution of individual requirements about the mean. However, RNIs themselves are not useful for predicting the requirements of individuals; more direct means are needed for accurate assessment.

In summary, the present data on Canadian women support the findings of previous reports that emphasize the gap between observed and recommended levels of energy requirements in individuals and suggest that current RNIs inadequately provide for energy requirements in middle-aged women. Given that RNIs for women over 75 years are 21% less than those presently explored, similar questions require attention in older populations. Clearly, a need exists to better define energy needs in Canadians, given the likelihood that present RNI values for energy substantially underestimate actual values.

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