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Validation of dietary intakes of protein and energy against 24 hour urinary N and DLW energy expenditure in middle-aged women, retired men and post-obese subjects: comparisons with validation against presumed energy requirements

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Objectives: To compare validation of reported dietary intakes from weighed records against urinary nitrogen excretion and energy expenditure measured by DLW, and to examine the utility of the Goldberg cut-off for EI:BMR in the identification of under-reporters.
Design: Energy (EI) and nitrogen (protein) intake (NI) were measured by 16 d of weighed diet records collected over 1 y. They were validated against urinary nitrogen excretion in 5–8 (mean 6.0) 24 h urine collections and total energy expenditure (EE) measured by doubly labelled water (DLW). Basal metabolic rate (BMR) as measured by whole body calorimetry in women or bedside ventilated hood (Deltatrac) in men. Individual subjects were identified as under-reporters if Urine N:NI was >1.00 or if EI:EE was <0.79. The agreement between the two ratios in detecting under-reporting was examined. The results from the direct validation by DLW were also compared with validation using the Goldberg cut-off for EI:BMR (Goldberg *et al*, 1991).
Subjects: Eighteen women aged 50–65 y and 27 men aged 55–87 y were selected from participants in two larger dietary surveys as representing the full range of dietary reporting as measured by Urine N:NI. Data from a previous study of 11 post-obese subjects were also included.
Results: The two ratios, Urine N:NI and EI:EE, were significantly related ($r = -0.48$, $P < 0.01$). Using the above cut-offs, seven (4F, 3M) subjects were identified as under-reporters by both methods, one (1M) by Urine N:NI only and 8 (3F, 5M) by EI:EE only. There was close agreement in post-obese subjects where 6 subjects showed a substantial degree of under-reporting by both methods ($r = -0.87$, $P < 0.001$). The correlation between direct validation by DLW and EI:BMR_{est} was 0.65 ($P < 0.001$). Some limitations of the Goldberg cut-off for identifying individual under-reporters were demonstrated.
Conclusions: EI:EE provides an estimate of the degree of under-reporting of energy at the group and individual level. Urine N:NI identifies under-reporting of protein intake and the most obvious under-reporters of energy, but is probably of lesser value in estimating the overall degree of under-reporting of energy at group level. Good validation by EI:BMR depends on knowledge of physical activity at both group and individual level. However, the correlation of 0.65 between EI:EE and EI:BMR_{est} suggests that EI:BMR could be usefully incorporated into analysis of data from epidemiological studies. Validation measures consisting of at least predicted EI:BMR ratios and urinary measures should be incorporated into dietary surveys.
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Descriptors: dietary assessment; validation; urinary N excretion; doubly labelled water

Introduction

During the 1970s and 1980s, statistical approaches to dietary data enhanced understanding of the limitations of dietary assessment (see Basiotis *et al*, 1989; Basiotis *et al*, 1987; Beaton *et al*, 1983; Liu *et al*, 1978). However, these approaches assumed that the data collected was associated with random rather than systematic measurement error. The 1980s saw the development of biomarkers to validate reported food intakes. Two have proved particularly helpful. The first is the use of 24 h urinary nitrogen excretion (Urine N) to validate reported nitrogen (protein) intake first proposed by (Isaksson, 1980) and further developed by (Bingham & Cummings, 1983; Bingham & Cummings, 1985). The second technique is the use of the measurement of energy expenditure by doubly labelled water (Schoeller & van Santen, 1982) to validate reported energy intake (Bandini *et al*, 1987; Black *et al*, 1993; Haggarty & McGaw, 1988; Prentice *et al*, 1986). The use of biomarkers that are independent of the behavioural changes induced by the act of recording or reporting food intake has shown that systematic measurement errors may be present even in those methods assumed to be the most accurate such as weighed records and that an assumption that dietary records are valid is no longer tenable.

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With the exception of one small study on post-obese subjects (Black *et al*, 1995), the two techniques have not been used simultaneously. Both have independently provided clear evidence for under-estimation of food intake. However, understanding of this problem has as yet not progressed much beyond a demonstration of its existence. Many questions remain to be answered. This paper presents data from two studies in which Urine N and DLW were used together to validate reported dietary intakes, and examines their relative ability to identify under-reporters at the individual level.

In 1991, Goldberg and colleagues extended the principle of validating energy intake against measured energy expenditure to validating energy intake against energy requirements. In this technique mean energy intake is expressed as a multiple of the mean BMR estimated from equations (Schofield *et al*, 1985) and compared with the presumed mean energy requirement of the population also expressed as a multiple of the BMR (known as Physical Activity Level or PAL). The Goldberg equation calculates the cut-off value of EI:BMR below which it is unlikely that the mean intake represents either habitual intake or a random low intake. It makes allowance for the errors associated with the number of subjects studied (n), the length of dietary assessment (k days), and variation in food intake, BMR and physical activity. This technique has demonstrated that under-reporting is widespread. Approximately two thirds of 37 studies examined had a mean reported energy intake below the Goldberg cut-off (Black *et al*, 1991). It has also provided a tool for others to investigate the problem.

The Goldberg equation was designed to evaluate the overall bias to under-reporting in mean energy intakes. However, the cut-off value calculated for $n = 1$ can be used to identify under-reporters at the individual level. For example, several authors (Price *et al*, 1993, 1997; Pryer *et al*, 1997; Rutishauser *et al*, 1994) have examined the characteristics of 'Low Energy Reporters' defined as those with EI:BMR ratio below a cut-off that assumed an energy requirement of about $1.55 \times$ BMR. However, this criterion can only identify under-reporters among those with a sedentary lifestyle. Any large dietary survey will include subjects with both high and low energy expenditures and the pattern of under-reporting across the full range is still unknown. The present study examined the data for the presence of under-reporters at higher energy expenditures and for the limitations of the Goldberg cut-off in identifying under-reporters.

Methods

Outline of the study

Energy (EI) and nitrogen (NI) intake were assessed by 4 d weighed records in each of four seasons (16 d in total). Urinary nitrogen excretion (two 24 h collections in each of the 4 seasons) (Urine N) was also measured. These data were obtained from women in a study to determine the best dietary assessment method to use in the European Prospective Investigation of Cancer (EPIC) (Bingham *et al*, 1995; Bingham *et al*, 1994) and a study of mainly retired men (Johansson *et al*, in preparation). The present study additionally measured energy expenditure (EE) by DLW and basal metabolic rate (BMR). Data from a previous study of post-obese subjects (Black *et al*, 1995) has also been included.

Recruitment: Women

For the main study of women, all those aged 50–65 y from the lists of two general practices in Cambridge were contacted by post. Those expressing interest in a detailed study of diet were contacted by telephone and visited at home and, if still willing, were entered into the study. No exclusions were made on the grounds of ill health. One hundred and sixty women completed the study. They were studied in two groups. Immediately before the fourth season, the eighty women in the second group were asked if they were willing to have their metabolic rate measured by doubly labelled water and calorimetry. Subjects were chosen from among those who were willing to participate and who eventually provided at least 5 valid 24 h urine collections. The intention was that the DLW measurement would span the 4 d of diet records. Unfortunately, owing to a scarcity of water enriched with ^{18}O at that time and a consequent unanticipated price increase, the study was limited to 18 subjects and delayed in some subjects until after completion of the final diet records. Median (range) time elapsed between final diet records and DLW measurement was 0.8 (-4 to $+4$) weeks. The 18 subjects were selected to represent the range of Urine N:NI found in the first three seasons. The number eventually obtained from each fifth of the distribution of Urine N:NI was 4 (lowest), 5, 2, 4 and 3 (highest).

Recruitment: Men

In the main study, men aged 55–87 y were recruited from three sources. Husbands of women who had participated in the earlier similar study, men that had previously taken part in an osteoporosis study, and men from the list of one general medical practice were invited to participate by letter. All those responding were contacted by phone and visited at home for further explanations and enrolled on the study if willing to participate. No exclusions were made on the grounds of ill health. Seventy-six men completed the main study. For the present study, subjects were approached for DLW and BMR measurements only after completion of the final diet records. They were selected to represent the range of the ratio of Urine N:NI found. Twenty-seven subjects were studied, the number eventually obtained from each fifth of the distribution of Urine N:NI in the main study being 5 (lowest), 5, 6, 5 and 5 (highest). Owing to organisational problems and difficulties in recruiting, the median (range) time elapsed between the final diet records and the DLW measurement was 15 (2–52) weeks.

Recruitment: Post-obese subjects

Subjects were recruited by advertisement as having lost more than 28 pounds (12.7 kg) and maintained that weight loss for more than six months. Ten women and one man were enrolled on the study. Energy expenditure from DLW was assessed simultaneously with the other investigations.

Dietary assessment: Women and men

Subjects were instructed to weigh each individual food item using cumulative weighing and to provide notes on ingredients of composite dishes with approximate quantities. Weighing was by the PETRA system (Cherlyn Electronics, Cambridge). The weight and a spoken description of each food item were automatically recorded onto a cassette tape. A special console was used to recover the information which was transcribed and then coded manually for computer analysis (women's study) or using a computerised entry system, DIDO (Paul *et al*, unpublished) (men's study).

Nutrient intake was calculated using the fourth edition of McCance & Widdowson's The Composition of Foods (Paul & Southgate, 1978) and the Dunn Nutrition Centre's supplementary database of additional recipes (Wiles *et al*, 1980) and manufacturers' information. The third (Holland *et al*, 1988) and fourth (Holland *et al*, 1989) supplements to the fourth edition were additionally used to calculate nutrient intake from the mens' data.

Dietary assessment: Post-obese

The subjects kept weighed diet records using the PETRA system for 10–11 d and traditional digital scales and notebook for 10–11 d. Subjects kept 21 d of records in total. Diet records were analysed using McCance & Widdowson's The Composition of Food, fourth edition (Paul & Southgate, 1978) with additional recipes (Wiles *et al*, 1980) and manufacturers' information.

Basal metabolic rate

All subjects were brought to the unit for an evening meal of approximately one third of energy requirements taken as $1.4 \times \text{BMR}$ estimated from equations (Schofield *et al*, 1985). The women and the post-obese subjects then spent the night in a whole body calorimeter. They were woken to pass urine at 6.30 am, subsequently returning to sleep. They were woken for BMR to be measured between 8 am and 9 am at a temperature of 23°C.

The men spent the night in a bedroom of the metabolic suite and BMR was measured at the bedside using a metabolic cart (Deltatrac) with a ventilated hood. At 6.30 am they were woken to pass urine, subsequently returning to bed. After a period of 30 min quiet rest, a large transparent plastic hood was placed over the head, and measurements were commenced. After a period 10–15 min to obtain steady readings, BMR was measured for 10 min. BMR was calculated from the equation of Elia (Elia & Livesey, 1992).

$$\text{BMR (kJ/min)} = (15.818 + (5.176^*\text{RQ}) \times \text{VO}_2(1/\text{min})$$

Total energy expenditure

A baseline urine specimen was obtained at 6.30 am on the day of the BMR measurement. The subject then drank the doubly labelled water containing 0.07 g ^2H_2O and 0.174 g $H_2{}^{18}O$/kg body weight (women and men) or 0.046 g ^2H_2O and 0.174 g $H_2{}^{18}O$/kg body weight (post-obese subjects). Urine samples were obtained from the second voiding of the day on each of the following 14 d (21 d in the post-obese). In the men only, seven baseline urine samples were also obtained on each of the seven days preceding the BMR measurement and administration of the DLW dose. This was done to provide an estimate of the contribution of natural abundance variation of the isotopes to the precision of the method (Ritz *et al*, 1996). Isotope enrichments were measured using an isotope-ratio mass spectrometer (Aqua Sira, Middlewich, Cheshire) and pool sizes were calculated by extrapolation. The mean (s.d.) ratio of ^2H and ^{18}O spaces was 1.035 (0.013) in the women, 1.033 (0.009) in the men and 1.037 (0.014) in the post-obese subjects. Energy expenditure was calculated using the multipoint technique (Coward, 1988). Individual FQ were calculated from dietary data (Black *et al*, 1986).

Urinary nitrogen

Twenty-four hour urine collections were made using boric acid as a preservative in the collecting container as described by (Bingham *et al*, 1995). In each season, two 24 h urine collections were obtained, one during the 4 d period of diet records and one in the 2 d immediately following. The post-obese made five collections within the 21 d period of diet records. Completeness of collection was verified by PABACHEK (Bingham & Cummings, 1983). Three capsules containing 80 mg of para-aminobenzoic acid (PABA) were taken, one on rising and one each with the midday and evening meals. Urine collections containing less than 205 mg (85% of the dose) were rejected as incomplete. Nitrogen in urine was measured by Kjeldahl technique.

Validation of nitrogen intake

For subjects in nitrogen balance, Urine N reflects nitrogen intake (NI). Validation is by comparison of NI with Urine N expressed as the ratio Urine N:NI. A *higher* than expected ratio of Urine N:NI reflects either incomplete reporting of nitrogen (protein) intake, or a reduced (low energy) intake leading to oxidisation of protein to supply energy. Although the expected ratio is 0.81 ± 0.05 (Bingham & Cummings, 1985), the ratio is skewed in free-living individuals with no clear bimodal distribution which would suggest a cut-off point between 'valid' and 'invalid' records (Bingham *et al*, 1995). In the main study of women subjects were divided into fifths of the distribution according to the ratio of Urine N:NI. It was found that those in the top fifth (with ratios from 1.00–1.47) had significantly lower energy intake, higher body weight, higher BMI, and higher restrained eating scores than those in the lower four fifths (with ratios from 0.68–0.99) (Bingham *et al*, 1995). For the present study therefore a cut-off of 1.00 was chosen on the basis that individuals whose value was greater than this were clearly different from the rest in a number of variables. Subjects with a ratio Urine N:NI *greater* than 1.00 were deemed under-reporters.

Validation of reported energy intake

For people in energy balance, habitual energy intake must equal energy expenditure. The assumption is made that individuals are in energy balance and that a single dietary assessment (by whatever technique) provides a valid measure of habitual intake and that a single 14 d measure by DLW provides a valid measure of EE. Validation is by direct comparison of EI with EE expressed as the ratio EI:EE. The expected ratio is 1.00 and the 95% confidence limits in the present study were 0.79–1.21 (based on mean within subject CV on daily energy intake of 20.8% and of repeat DLW measurements of 8.9% (Black *et al*, 1996)). Subjects with a ratio EI:EE *less* than 0.79 or *greater* than 1.21 were deemed under- or over-reporters respectively.

Under-reporting is somewhat confusingly indicated by *high* values of Urine N:NI but *low* values of EI:EE. However, since each ratio has been established independently in previous publications and is in the form that best represents the underlying concepts, it was decided to maintain the original configuration for the present study.

EI:BMR and the Goldberg cut-off

The EI:BMR ratio was calculated for each subject using both measured BMR (BMR_{meas}) and BMR estimated (BMR_{est}) from equations (Department of Health, 1991).

The Goldberg cut-off was calculated from the equation

$$\text{Cut-off value for EI:BMR} = \text{PAL} \times \exp\left[\text{SD}_{\min} \times \frac{(\text{S}/100)}{\sqrt{\text{n}}}\right]$$

where PAL is the assumed average physical activity level for the population under study, SD_{min} is -2 for 95% or -3 for 99% confidence limits, *n* is the number of subjects, and *S* is the overall CV for PAL, taking into account the variability in energy intake and basal metabolic rate. *S* is given by the equation

$$S = \sqrt{[CV_{Iw}^2/k + CV_B^2 + CV_P^2]}$$

where CV_{Iw} is the within-subject variation in energy intake (taken as 23%) (Bingham, 1987), *k* is the number of days of diet assessment, CV_B is the variation in repeated BMR measurements (taken as 2.5%) (Prentice *et al*, 1989) or the precision of estimated compared with measured BMR (taken as 8.0%) (Schofield *et al*, 1985), and CV_P is the between-subject variation in PAL (taken as 12.5% here) (FAO/WHO/UNU, 1985).

The Goldberg cut-off was calculated for $n = 1$ using both BMR_{meas} and BMR_{est} and three alternatives for PAL: first, the mean population PAL for a sedentary lifestyle of 1.55, second, a study-specific mean PAL for women (1.66), men (1.86) and post-obese (1.59) as measured, and third, the subject-specific PAL as measured. Table 1 shows the calculated cut-off values for each situation except the last. Subjects in each category with EI:BMR below the Goldberg cut-off were designated under-reporters.

Statistics
Differences between groups were tested by Student's *t*-test. All protocols were approved by the Dunn Nutrition Centre Ethical Committee.

Results

Subjects
Anthropometric characteristics of the subjects are shown in Table 2.

Validation of intake at the group level
Nitrogen intake and excretion and the ratio of Urine N:NI are shown in Table 2. There was no significant difference between women and men in the mean (s.d.) ratio Urine N:NI, 0.90 (0.13) *vs* 0.85 (0.13). The value for the post-obese subjects, 1.15 (0.42), was significantly greater than that of the men ($P < 0.05$). All three values were greater than the expected ratio of 0.81 (Bingham & Cummings, 1985) indicating bias to under-reporting of protein intake. The correlation between urine N and NI was 0.69 ($P < 0.001$).

The mean energy intake and energy expenditure and the ratio of EI:EE are shown in Table 2. There were no significant differences between women and men in the mean (s.d.) ratio of EI:EE, 0.89 (0.17) *vs* 0.88 (0.18). The mean (s.d.) ratio EI:EE was 0.89 (0.18) compared with an expected ratio of 1.00, indicating a bias to under-reporting of about 11% for energy. EI:EE was significantly lower in the post-obese subjects than in both women and men, mean (s.d.) EI:EE 0.73 (0.19) compared with 0.89 (0.18), $P < 0.05$, indicating a greater bias to under-reporting in this group. The correlation between EE and EI was 0.47 ($P < 0.001$).

Table 2 also shows the mean BMR_{meas} for each group and EI and EE both expressed as multiples of BMR_{meas}. There were significant differences between all groups for EI:BMR_{meas} (women *vs* men, women *vs* post-obese, $P < 0.05$; men *vs* post-obese, $P < 0.001$). Energy expenditure in the men, expressed as EE:BMR_{meas}, was significantly higher than that of women ($P < 0.02$) and the post-obese ($P < 0.001$). In all three groups EI:BMR_{meas} were lower than the Goldberg cut-off calculated using the study-specific PAL indicating bias to under-reporting. If however, no measure of energy expenditure had been available and a sedentary life-style of PAL = 1.55 had been assumed for calculating the cut-off, then only the post-obese subjects would have been described as under-reporting. This highlights the need to use an appropriate PAL when evaluating under-reporting.

Validation at the individual level
Figure 1 shows the relationship between Urine N:NI and EI:EE. There were no significant differences between women and men in these ratios, and the data were combined. The dashed lines show the expected ratios. For EI:EE the dotted lines show the 95% confidence limits as defined under methods. Under-reporters are deemed to be those with EI:EE *less* than 0.79. For Urine N:NI the dotted line marks the cut-off (1.00) above which under-reporting is deemed present as defined under methods. Seven subjects (4F, 3M) were identified as under-rerporters by both validations; one (1M) by Urine N:NI only and eight (3F, 5M) by EI:EE only. The correlation between the two ratios was -0.43 in men, -0.59 in women, and for men and women together was -0.48 ($P < 0.01$) (Table 2).

In Figure 2 the data for the highly selected postobese subjects are shown superimposed on Figure 1 There was a dichotomy in the data. Four subjects were among the 'valid' reporters, whereas six were clear under-reporters by both validation techniques, three of whom had particularly high Urine N:NI ratios. The correlation between the

Table 1 Goldberg cut-off calculated for individuals using standard factors for CV_{Iw}, CV_B and CV_P, study specific PAL, study specific days of dietary assessment, $SD_{min} = -2$, and $n = 1$

Group	*BMR*	*PAL*	CV_{Iw}	CV_B	CV_P	*k days*	*n subjects*	S^a	*Cut-off*[a]
'Sedentary'	Estimated	1.55	23.0	8.0	12.5	16	1	15.92	1.13
	Measured	1.55	23.0	2.5	12.5	16	1	13.98	1.17
Women	Estimated	1.66	23.0	8.0	12.5	16	1	15.92	1.21
	Measured	1.66	23.0	2.5	12.5	16	1	13.98	1.25
Men	Estimated	1.86	23.0	8.0	12.5	16	1	15.92	1.35
	Measured	1.86	23.0	2.5	12.5	16	1	13.98	1.41
Post-obese	Estimated	1.59	23.0	8.0	12.5	21	1	15.67	1.16
	Measured	1.59	23.0	2.5	12.5	21	1	13.70	1.21

[a]See text for the equations for calculating *S* and the Cut-off value.

Table 2 Anthropometric measures, nitrogen intake and excretion, energy intake and expenditure, and dietary intake validation ratios for men and women in the present study and in a study of postobese subjects [Black *et al*, 1995]

	Women present study		*Men present study*		*All subjects present study*		*Post-obese (Black et al, 1995)*	
n	18		27		45		11	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
Age, y	57.9	4.6	67.5	5.03			35.6	0.10
Height, m	1.66	0.07	1.72	0.06			1.66	0.09
Weight, kg	68.8	9.3	74.7	10.7			64.7	8.3
BMI	25.0	3.9	25.4	3.6			23.6	2.8
Nitrogen intake, g	12.13	2.32	13.53	1.89	12.96	2.17	10.48	3.71
Nitrogen excretion	10.79	2.10	11.51	2.17	11.21	2.14	11.10	2.72
Urine N:NI	0.90	0.13	0.85	0.13	0.87	0.13	1.15	0.42
r (Urine N × NI)	0.77		0.62		0.69		0.66	
Energy intake, MJ	8.30	1.56	10.06	1.88	9.34	1.94	7.14	2.55
Energy expenditure, MJ	9.50	1.72	11.67	2.43	10.78	2.40	9.66	1.69
EI:EE	0.89	0.17	0.88	0.18	0.89	0.18	0.73	0.19
r (EE × EI)	0.45		0.28		0.47		0.75	
r (EI:EE × Urine N:NI)	−0.59		−0.43		−0.48		−0.97	
BMR_{meas}	5.71	0.62	6.28	0.90	6.05	0.84	6.08	0.94
EI:BMR_{meas}	1.45	0.22	1.61	0.28	1.55	0.27	1.16	0.32
EE:BMR_{meas} (PAL)	1.66	0.24	1.86	0.30	1.78	0.29	1.59	0.11
Goldberg cut-off for each study calculated using 95% confidence limits, measured BMR, and study specific *n* and *k* (days of diet assessment).								
for PAL = 1.55	1.45		1.47		1.49		1.43	
for study PAL	1.55		1.76		1.71		1.46	
r (EI:EE × EI:BMR_{meas})	0.68		0.68		0.65		0.97	

two ratios for the post-obese subjects was −0.87 ($P < 0.001$) (Table 2).

Figure 3A and 3B shows the EI:BMR_{meas} ratios for men and for women plotted against PAL (EE:BMR_{meas}). Under- and over- and valid-reporters, as defined by the direct comparison of EI:EE, are identified by different symbols. The horizontal lines indicate the Goldberg cut-off for $n = 1$ and PAL = 1.55 and also $n = 1$ and either PAL = 1.86 (men) or PAL = 1.66 (women). These figures show that there were under-reporters at all levels of energy expenditure and that the number of under-reporters identified by the Goldberg cut-off for EI:BMR_{meas} depended on the choice of PAL used to calculate the cut-off. Only 2 men and 2 women were identified a under-reporters if the 'sedentary' PAL of 1.55 was used, whereas 5 male and 4 female under-reporters were identified using the higher study-specific PAL of 1.66 in women and 1.86 in men. However, even if the study-specific PAL was used, 3 men and 3 women under-reporters remained unidentified. This indicates that even choosing the appropriate PAL for the group cannot identify all under-reporters, and suggests that knowledge of each subjects own PAL is required. Nevertheless, there were significant correlations between EI:EE and EI:BMR (0.67 in women and 0.65 in men, $P < 0.001$, Table 2) which suggests that EI:BMR is an indicator that could usefully be incorporated into the analysis of data from epidemiological studies.

Table 3 further explores the ability of EI:BMR to identify under-reporters. Columns 1–4 show the individual

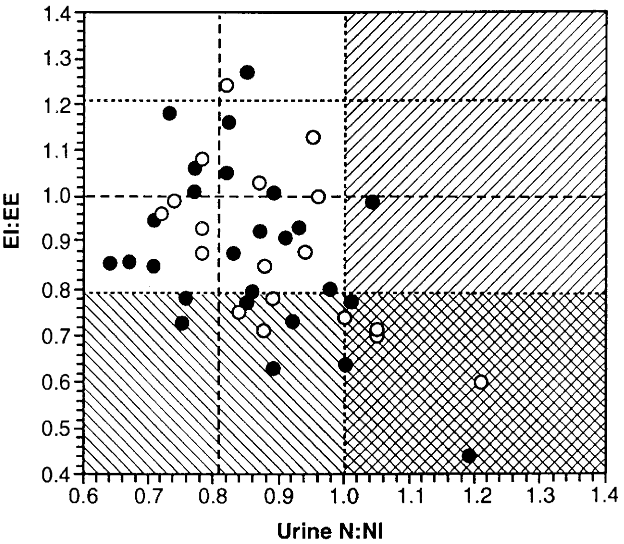

Figure 1 Relationship between validations against Urine N and DLW energy expenditure for men and women of the present study.

● Men
○ Women
——— Expected mean ratio for valid records.
.... 95% confidence limits of the agreement between EI and EE due to within-subject day to day variation in each measurement or cut-off at 1.00 for Urine N:NI.
▨ Area of under-reporting according to Urine N:NI.
▧ Area of under-reporting according to EI:EE.

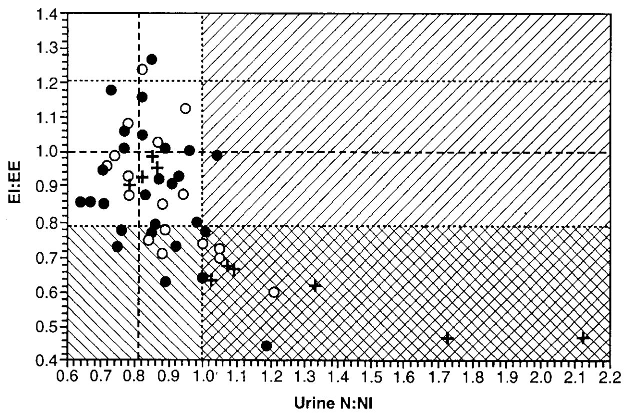

Figure 2 Data for post-obese subjects superimposed upon Figure 1

● Men (Present study)
○ Women (Present study)
+ Post-obese subjects (Black *et al*, 1995).

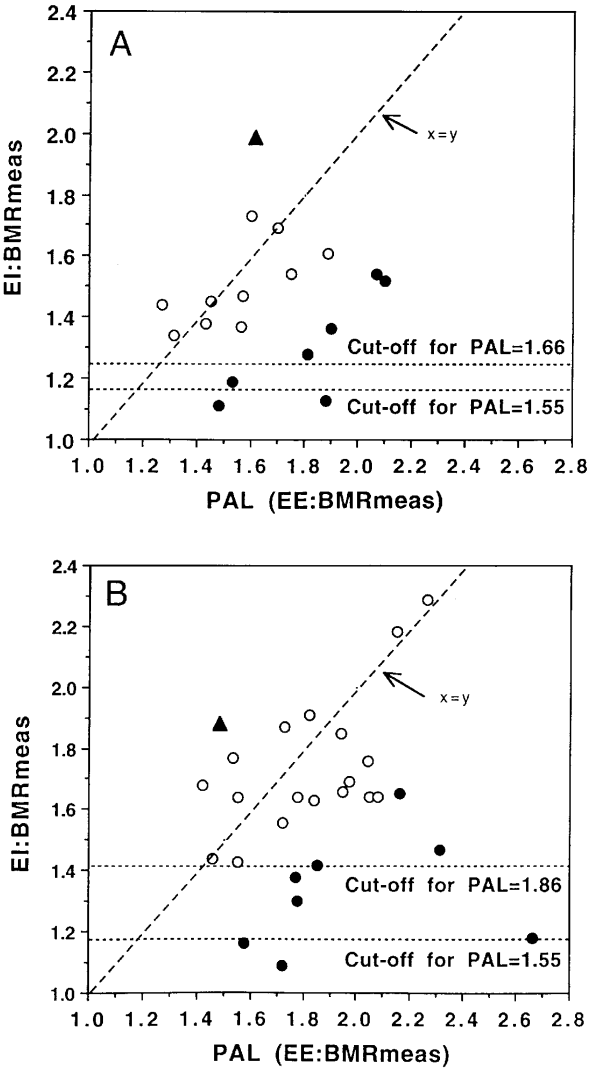

Figure 3 Relationship between energy expenditure expressed as EE:$BMR_{measured}$ and energy intake evaluated as EI:$BMR_{measured}$. The horizontal lines show the Goldberg cut-off for $n = 1$ and either PAL = 1.55 or the PAL specific to the study, (1.66 for women and 1.86 for men).

● under-reporters: EI:EE < 0.79
○ valid-reporters: EI:EE 0.79–1.21
▲ over-reporters: EI:EE > 1.21
A. Women B. Men

validations by Urine N:NI, EI:EE, EI:BMR_{est} and EI:BMR_{meas}. Within each group (men, women and post-obese) subjects are ranked according to the ratio EI:EE. Columns 5–10 show the difference between each subject's EI:BMR and the Goldberg cut-off for the criteria (PAL and BMR) at the head of the column. (The cut-off values are shown in Table 1). Negative values identify under-reporters and are shown in bold. The actual figures give an indication of whether a subject is a serious under-reporter or only borderline.

Among the men and the women taken together, the direct validation by doubly labelled water (EI:EE) identifies fifteen subjects (7 women, 8 men) as under-reporters (Column 3). Only 4 out of the 15 subjects are identified using the Goldberg cut-off for the sedentary PAL of $1.55 \times BMR_{meas}$ (Column 6). This increases to 7 subjects if the study-specific PAL and BMR_{meas} is used (Column 8), and 11 if the subject-specific PAL and BMR_{Meas} is used (Column 10). The latter comparison is effectively a repeat of the direct comparison of EI to EE, but with greater errors and confidence limits because BMR enters the comparison. Columns 7 and 9 show that if BMR_{est} was used for these calculations, then subjects not identified as under-reporters by the direct validation EI:EE were also included.

Among the post-obese subjects, the dichotomy in the data is clearly shown. Six subjects were identified as under-reporters by EI:EE and were also identified as under-reporters by all variations of EI:BMR. The low EI:EE ratio and high Urine N:NI ratio indicate a substantial degree of under-reporting in these subjects. This, together with a relatively low PAL (1.59), made under-reporters readily identifiable even using the sedentary PAL.

Discussion

Validation of dietary records against a variety of external markers is now accepted as desirable practice, but it is important to establish what different conclusions may be drawn from validation by different techniques.

For validation at group level, both Urine N:NI and EI:EE can indicate the presence of bias to under-reporting. EI:EE can also indicate the degree of bias in energy intake. Since energy imbalance is undetectable in the time scale of a dietary assessment with the techniques available, energy balance may be assumed at the group level and the expected value for EI:EE is 1.00. In the present study over the twelve months from the beginning of the main study to the time of DLW measurement there was no change in the mean (s.d.) weight of the women, (68.4 ± 9.3 *vs* 68.5 ± 9.4 kg and a fall of only -0.9 kg in the men, 75.9 (10.5) *vs* 75.0 (10.7 kg). The assumption of energy balance at the group level is thus reasonable. The use of 24 h urine N to estimate NI also depends on the assumption that subjects are in a steady state, where intake equals output and may be influenced by the level of protein intake and the level of NSP in the diet; the latter increases bacterial and faecal N output and therefore reduces 'apparent' digestibility (Stephens & Cummings, 1979). In individuals consuming normal Western type diets low in NSP and containing relatively high amounts of mixed protein sources, the expected value is 0.81 ± 0.05 (Bingham & Cummings, 1985). Alternatively, an allowance of 2 g for faecal N is made (Isaksson, 1980). In spite of the assumptions made and the fact that the two validation ratios relate to different items of diet, they were in broad agreement with $r = -0.48$ ($P < 0.01$) in the men with women and $r = -0.87$ in the post-obese and the severest under-reporters were identified by either measure.

For the men and women together, the correlation between Urine N and NI was 0.69 and between EE and EI was 0.47. This suggests that urinary N excretion more closely reflects dietary N than energy expenditure reflects energy intake in the short term. Urinary N excretion may be more useful than DLW measurements at correctly identifying individual under-reporters, although poorer at estimating the overall bias to under-reporting. However, an alternative explanation could be that urinary N was measured simultaneously with dietary assessment whereas DLW measurements were made after completion of dietary studies. This is further discussed below.

From Figure 1, it is clear that there was not absolute agreement between the validations at the individual level. There are several possible reasons for this including the way the cut-off was defined, underestimation of the errors involved in the measurements, lack of coincidence in this

Table 3 Validation of individual energy intakes using the Goldberg cut-off calculated with varying factors. The figures in columns 5 to 10 are the difference between the subject EI:BMR and the Goldberg cut-off calculated using the factors at the head of the column. Negative values (in bold) identify under-reporters

					EI:BMR—Goldberg cut-off					
					PAL of 1.55 × BMR		*Study specific PAL*		*Subject PAL*	
	UrN:NI	*EI:EE*	*EI:BMRe*	*EI:BMRm*	*BMRe*	*BMRm*	*BMRe*	*BMRm*	*BMRe*	*BMRm*
	1	2	3	4	5	6	7	8	9	10
Women present study	**1.21**	**0.60**	1.01	1.13	**−0.12**	**−0.04**	**−0.20**	**−0.12**	**−0.35**	**−0.29**
(PAL = 1.66)	**1.05**	**0.70**	1.27	1.28	0.14	0.11	0.06	0.03	**−0.04**	**−0.09**
	0.88	**0.71**	1.26	1.36	0.13	0.19	0.05	0.11	**−0.12**	**−0.08**
	1.05	**0.72**	1.38	1.52	0.25	0.35	0.17	0.27	**−0.15**	**−0.07**
	1.00	**0.74**	1.68	1.54	0.55	0.37	0.47	0.29	0.17	**−0.02**
	0.84	**0.75**	1.10	1.11	**−0.03**	**−0.06**	**−0.11**	**−0.14**	0.02	**−0.01**
	0.89	**0.78**	1.14	1.19	0.01	0.02	**−0.07**	**−0.06**	0.03	0.03
	0.88	0.85	1.61	1.61	0.48	0.44	0.40	0.36	0.23	0.18
	0.78	0.88	1.76	1.54	0.63	0.37	0.55	0.29	0.49	0.22
	0.94	0.88	1.47	1.37	0.34	0.20	0.26	0.12	0.33	0.19
	0.78	0.93	1.41	1.47	0.28	0.30	0.20	0.22	0.26	0.28
	0.72	0.96	1.19	1.38	0.06	0.21	**−0.02**	0.13	0.15	0.30
	0.74	0.99	1.81	1.69	0.68	0.52	0.60	0.44	0.58	0.40
	0.96	1.00	1.64	1.45	0.51	0.28	0.43	0.20	0.59	0.35
	0.95	1.13	1.58	1.44	0.45	0.27	0.37	0.19	0.66	0.48
	0.87	1.03	1.32	1.34	0.19	0.17	0.11	0.09	0.36	0.35
	0.78	1.08	1.56	1.73	0.43	0.56	0.35	0.48	0.40	0.52
	0.82	1.24	2.26	1.99	1.13	0.82	1.05	0.74	1.09	0.78
Men present study	**1.19**	**0.44**	1.01	1.18	**−0.12**	0.01	**−0.34**	**−0.23**	**−0.93**	**−0.83**
(PAL = 1.86)	0.89	**0.63**	0.99	1.09	**−0.14**	**−0.08**	**−0.36**	**−0.32**	**−0.26**	**−0.21**
	1.00	**0.64**	1.53	1.47	0.40	0.30	0.18	0.06	**−0.15**	**−0.27**
	0.75	**0.73**	1.02	1.16	**−0.11**	**−0.01**	**−0.33**	**−0.25**	**−0.13**	**−0.04**
	0.92	**0.73**	1.30	1.30	0.17	0.13	**−0.05**	**−0.11**	0.01	**−0.04**
	0.85	**0.77**	1.40	1.65	0.27	0.48	0.05	0.24	**−0.16**	0.02
	1.01	**0.77**	1.37	1.42	0.24	0.25	0.02	0.01	0.02	0.02
	0.76	**0.78**	1.31	1.38	0.18	0.21	**−0.04**	**−0.03**	0.02	0.04
	0.86	0.79	1.62	1.64	0.49	0.47	0.27	0.23	0.11	0.07
	0.98	0.80	1.25	1.64	0.12	0.47	**−0.10**	0.23	**−0.24**	0.10
	1.04	0.99	1.27	1.44	0.14	0.27	**−0.08**	0.03	0.21	0.34
	0.71	0.85	1.57	1.66	0.44	0.49	0.22	0.25	0.15	0.19
	0.67	0.86	1.40	1.69	0.27	0.52	0.05	0.28	**−0.03**	0.21
	0.64	0.86	2.07	1.76	0.94	0.59	0.72	0.35	0.59	0.22
	0.83	0.88	1.61	1.63	0.48	0.46	0.26	0.22	0.27	0.24
	0.91	0.91	1.59	1.56	0.46	0.39	0.24	0.15	0.34	0.26
	0.87	0.92	1.46	1.64	0.33	0.47	0.11	0.23	0.17	0.30
	0.93	0.93	1.65	1.43	0.52	0.26	0.30	0.02	0.53	0.26
	0.71	0.95	1.96	1.85	0.83	0.68	0.61	0.44	0.55	0.39
	0.89	1.01	1.71	2.18	0.58	1.01	0.36	0.77	0.15	0.56
	0.77	1.01	2.08	2.29	0.95	1.12	0.73	0.88	0.44	0.58
	0.82	1.05	1.94	1.91	0.81	0.74	0.59	0.50	0.62	0.53
	0.77	1.06	1.68	1.64	0.55	0.47	0.33	0.23	0.55	0.47
		1.08	1.88	1.87	0.75	0.70	0.53	0.46	0.62	0.56
	0.82	1.16	1.50	1.77	0.37	0.60	0.15	0.36	0.38	0.62
	0.73	1.18	1.51	1.68	0.38	0.51	0.16	0.27	0.47	0.60
	0.85	1.27	1.99	1.88	0.86	0.71	0.64	0.47	0.92	0.77
Post-obese	**1.72**	**0.46**	0.63	0.64	**−0.50**	**−0.53**	**−0.53**	**−0.57**	**−0.40**	**−0.42**
(Black *et al* (1995)	**2.12**	**0.46**	0.76	0.72	**−0.37**	**−0.45**	**−0.40**	**−0.49**	**−0.39**	**−0.48**
(PAL = 1.59)	**1.33**	**0.61**	1.09	1.03	**−0.04**	**−0.14**	**−0.07**	**−0.18**	**−0.13**	**−0.24**
	1.02	**0.63**	1.02	1.06	**−0.11**	**−0.11**	**−0.14**	**−0.15**	**−0.21**	**−0.22**
	1.09	**0.66**	0.95	0.98	**−0.18**	**−0.19**	**−0.21**	**−0.23**	**−0.13**	**−0.14**
	1.07	**0.67**	1.08	1.09	**−0.05**	**−0.08**	**−0.08**	**−0.12**	**−0.10**	**−0.14**
	0.99	0.80	1.26	1.37	0.13	0.20	0.10	0.16	0.01	0.06
	0.78	0.90	1.25	1.28	0.12	0.11	0.09	0.07	0.22	0.20
	0.82	0.92	1.45	1.57	0.32	0.40	0.29	0.36	0.20	0.27
	0.86	0.95	1.83	1.55	0.70	0.38	0.67	0.34	0.63	0.31
	0.85	0.98	1.67	1.53	0.54	0.36	0.51	0.32	0.52	0.34
Percent Under-reporters										
Women	33	39			11	11	22	17	22	33
Men	19	30			11	7	26	15	26	19
Post-Obese	63	55			55	55	55	55	55	55

study in the timing of measurements, and differential reporting of energy and nitrogen.

Definition of cut-off points
The cut-off for Urine N:NI was defined with reference to observed findings in 160 women (Bingham *et al*, 1995). As no clear bimodal distribution was evident in the study, the cut-off was defined as the value of the fifth quintile (80th percentile), subjects in the top fifth of the distribution having been shown to be significantly different from subjects in the fourth and lower fifths in several parameters including reported energy and nitrogen intakes. Subjects with values greater than 1.00 can be expected to be undoubted under-reporters. The cut-off for EI:EE on the other hand was defined statistically as the confidence limits around the mean taking into account known daily variation in each measurement. The lower boundary (0.79) lies near the 40th percentile of the distribution in this study thus defining two fifths of the distribution as under-reporters compared with one fifth of the Urine N:NI distribution.

Confidence limits of the methods
The confidence limits ascribed to measures of energy intake take into account the day to day variation found in the present study. There are however, many potential sources of error in dietary assessments the size and direction of which are largely unknown. They are generally assumed to cancel each other out at the group level, but may well introduce large errors at the individual level.

Time elapsed between measurements
Urine N was measured at the time of the dietary recording, both measurements being spread over four seasons, whereas energy expenditure was measured after completion of the dietary records. The median (range) time lapse was 1 (-4 to $+4$) w for the women and 15 (2–52) w for the men.

However, this time lapse may be unimportant in this group. Energy balance is not expected to be achieved over the few days of a diet study, and it is not therefore essential for the DLW and dietary measurements to be concurrent. Known within-subject variation in DLW measurements in subjects with no apparent change in activity (Black *et al*, 1996) was incorporated into the confidence limits and this was a retired group with a regular lifestyle. Information collected from the subjects did not suggest any marked changes in physical activity over the time of the study. However, lack of agreement between intake and expenditure might be due to differences in seasonal activity when measures are widely spaced. Dietary records in this study included measures in all four seasons. DLW measurements were in the winter months (October to March) in all women and 9 men, and in the summer months (April to September) in 18 men. There was no difference in EI:EE between winter and summer months; mean (s.d.) were 0.88 (0.18) and 0.90 (0.18) respectively. Nor was there any correlation between EI:EE and the lapse of time from last diet record to DLW measurement ($r = 0.90$).

If there was poorer agreement between reported intake and energy expenditure in men with the longest gap between measurements, this could indicate that a long gap was inappropriate for validation of intake. However, EI:EE for men with DLW measurements ≤ 15 w and > 15 w after the final diet records were 0.85 (0.19) and 0.96 (0.14) indicating less under-reporting in those studied furthest from completion of diet records. This reflects the pattern of recruiting in that those with severest under-reporting by Urine N:NI were the first to be approached. It gives no suggestion that the agreement became worse as time between the EI and EE measurements increased and provides support for the view that energy expenditure was neither highly variable within subject nor likely to have changed over the time period studied.

Differential reporting of energy and nitrogen
There is evidence from other studies of differential reporting of foods and nutrients between low and high energy reporters (Bingham *et al*, 1995; Pryer *et al*, 1997; Rutishauser *et al*, 1994; Price *et al*, 1997). Not only is the total intake of macronutrients lower, but the proportion of energy derived from each is altered. All four studies cited reported a higher proportion of energy derived from protein and a low proportion from sugars. Changes in energy derived from fat and starch were generally smaller and not consistent in direction. In a small observational study in a metabolic facility (Poppitt *et al*, 1995) found that main meals were well reported, but snacks very poorly reported. This was reflected in 100% reporting of protein, but only 86% for energy.

EI:BMR for evaluating reported energy intake
Doubly labelled water measurements are not available as a routine technique for validating energy intake in all surveys. The use of EI:BMR estimated from body weight and the Goldberg cut-off provides an alternative. The Goldberg equation was designed to identify under-reporting at the group level. In their original publication Black *et al* (1991) chose $1.55 \times$ BMR as the yardstick because evidence from energy studies suggested this as the appropriate level for a sedentary lifestyle. However, a recent review of global DLW data (Black *et al*, 1996) suggests that PAL for normally active free-living people are higher than 1.55 in all age-sex groups except those over 75y. The extent and degree of under-reporting has probably been under- rather than over-estimated. However, provided there is sufficient information about the physical activity of a group under study, an appropriate PAL can be chosen and EI:BMR used to evaluate the possible degree of under-reporting at the group level.

The use of the Goldberg techniques has been extended to identify under-reporting at the individual level and its use for this purpose is more problematical. The data in the present study show that under-reporting is present at all levels of energy expenditure, and that the Goldberg cut-off for $n = 1$ and PAL of 1.55 will identify very few individual under-reporters if the average PAL for the group is significantly higher than 1.55. The proportion identified increases if more appropriate group mean PAL are used and improves further if subject's own level of physical activity can be ascertained. It is therefore desirable that dietary surveys should collect not only data on weight for the calculation of BMR, but also information about both occupational and leisure activity. The data in the present study suggest that using a measured BMR may eliminate a small number of gross mis-classifications due to wide discrepancies between measured and estimated BMR. This suggests that the inclusion of measurement of BMR is desirable in small scale research studies.

Conclusions

In summary, the use of independent validation measures such as those reported here in dietary surveys has enabled the presence of under-reporting to be documented. This is an important source of error in surveillance and research techniques and is likely to vary in extent and magnitude depending on the population studied.

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References

Bandini LG, Schoeller DA, Cyr HN & Dietz WH (1990): Validation of reported energy intake in obese and non-obese adolescents. *Am. J. Clin. Nutr.* **52**, 421–425.

Basiotis P, Thomas R, Kelsay J & Mertz W (1989): Sources of variation in energy intake by men and women as determined from one year's daily dietary records. *Am. J. Clin. Nutr.* **50**, 448–453.

Basiotis PP, Welsh SO, Cronin FJ, Kelsay JL & Mertz W (1987): Number of days of food intake records required to estimate individual and group nutrient intakes with defined confidence. *J. Nutr.* **117**, 1638–1641.

Beaton GH, Milner J, McGuire V, Feather TE & Little JA (1983): Sources of variance in 24-hour dietary recall data: implications of nutrition study design and interpretation. Carbohydrate sources, vitamins, and minerals. *Am. J. Clin. Nutr.* **37**, 986–995.

Bingham S (1987): The dietary assessment of individuals: methods, accuracy, new techniques and recommendations. *Nutr. Abstr. Rev.* **57**, 705–742.

Bingham S & Cummings JH (1983): The use of 4-amino benzoic acid as a marker to validate the completeness of 24-h urine collections in man. *Clin. Sci.* **64**, 629–635.

Bingham SA, Cassidy A, Cole TJ, Welch A, Runswick S, Black AE, Thurnham D, Bates CJ, Khaw KT, Key TJA & Day NE (1995): Validation of weighed records and other methods of dietary assessment using the 24h urine nitrogen technique and other biological markers. *Br. J. Nutr.* **73**, 531–550.

Bingham SA & Cummings JH (1985): Urine nitrogen as an independent validatory measure of dietary intake. *Am. J. Clin Nutr.* **42**, 1276–1289.

Bingham SA, Gill C, Welch A, Day K, Cassidy A, Khaw KT, Snayd MJ, Key TJA, Roe L & Day NE (1994): Comparison of dietary assessment methods in nutritional epidemiology: Weighed records versus 24h recalls, food frequency questionnaires and estimated diet records. *Br. J. Nutr.* **72**, 619–643.

Black AE, Coward WA, Cole TJ & Prentice AM (1996): Human energy expenditure in affluent societies: analysis of 574 doubly-labelled water measurements. *Eur. J. Clin. Nutr.* **50**, 72–92.

Black AE, Goldberg GR, Jebb SA, Livingstone MBE & Prentice AM (1991): Critical evaluation of energy intake data using fundamental principles of energy physiology: 2. Evaluating the results of dietary surveys. *Eur. J. Clin. Nutr.* **45**, 583–599.

Black AE, Jebb SA, Bingham SA, Runswick S & Poppitt S (1995): The validation of energy and protein intakes by doubly-labelled water and 24-hour urinary nitrogen excretion in post-obese subjects. *J. Hum. Nutr. Diet.* **8**, 51–64.

Black AE, Prentice AM & Coward WA (1986): Use of food quotients to predict respiratory quotients for the doubly-labelled water method of measuring energy expenditure. *Hum. Nutr: Clin. Nutr.* **40C**, 381–391.

Black AE, Prentice AM, Goldberg GR, Jebb SA, Bingham SA, Livingstone MBE & Coward WA (1993): Measurements of total energy expenditure provide insights into the validity of dietary measurements of energy intake. *J. Am. Diet. Ass.* **93**, 572–579.

Coward WA (1988): The doubly labelled-water ($^2H_2{}^{18}O$) method: principles and practice. *Proc. Nutr. Soc.* **47**, 209–218.

Department of Health (1991): Dietary reference values for food energy and nutrients for the United Kingdom. Report on Health and Social Subjects. London: HMSO.

Elia M & Livesey G (1992): Energy expenditure and fuel selection in biological systems: the theory and practice of calculations based on indirect calorimetry and tracer methods. *World Rev. Nutr. Diet.* **70**, 68–131.

FAO/WHO/UNU (1985): Energy and protein requirements. Report of a Joint FAO/WHO/UNU consultation. Technical Report Services Geneva: World Health Organisation.

Goldberg GR, Black AE, Jebb SA, Cole TJ, Murgatroyd PR, Coward WA & Prentice AM (1991): Critical evaluation of energy intake data using fundamental principles of energy physiology. 1. Derivation of cut-off values to identify under-recording. *Eur. J. Clin. Nutr.* **45**, 569–581.

Haggarty P & McGaw BA (1988): Energy expenditure of elite female athletes measured by the doubly-labelled water method. *Proc. Nutr. Soc.* **47**, 74A.

Holland B, Unwin ID & Buss DH (1989): *Milk Products and Eggs. The Fourth Supplement to McCance & Widdowson's The Composition of Foods* (4th edn). Cambridge: The Royal Society of Chemistry and Ministry of Agriculture, Fisheries and Food.

Holland B, Unwin ID & Buss DH (1988): *Cereals and Cereal Products. The Third Supplement to McCance & Widdowson's The Composition of Foods* (4th edn). Nottingham: The Royal Society of Chemistry and Ministry of Agriculture, Fisheries and Food.

Isaksson B (1980): Urinary nitrogen output as a validity test in dietary surveys. *Am. J. Clin. Nutr.* **33**, 4–5.

Liu K, Stamler A, Dyer A, McKeever J & McKeever P (1978): Statistical methods to assess and minimize the role of intraindividual variability in obscuring the relationship between dietary lipids and serum cholesterol. *J. Chron. Dis.* **31**, 399–418.

Paul AA & Southgate DAT (1978): *McCance & Widdowson's The Composition of Food*. London: HMSO.

Poppitt SD, Swann D, Black AE & Prentice AM (1995): Is under-reporting of energy intake in obese women macronutrient specific? Covert measurements in a metabolic facility. 6th European Congress of Obesity, June 1995, Copenhagen.

Prentice AM, Black AE, Coward WA, Davies HL, Goldberg GR, Ashford J, Sawyer M & Whitehead RG (1986): High levels of energy expenditure in obese women. *Br. Med. J.* **292**, 983–987.

Prentice AM, Goldberg GR, Davies HL, Murgatroyd PR & Scott W (1989): Energy-sparing adaptations in human pregnancy assessed by whole-body calorimetry. *Br. J. Nutr.* **62**, 5–22.

Price GM, Paul AA, Cole TJ, Hilder WS & Wadsworth MEJ (1993): Characteristics of people recording a low energy intake for body weight in a large national survey. *Proc. Nutr. Soc.* **52**, 343A.

Price GM, Paul AA, Cole TJ & Wadsworth MEJ (1997): Characteristics of the low-energy reporters in a longitudinal national dietary survey. *Br. J. Nutr.* Expected publication in June 1997 in *Br. J. Nutr*.

Pryer J, Vrijheid M, Nichols R, Kiggins M & Elliott P (1997): Who are the 'Low energy reporters' in the dietary and nutritional survey of British adults? *Int. J. Epidem.* **26**, 146–154.

Ritz P, Cole TJ, Couet C & Coward WA (1996): Precision of DLW energy expenditure measurements: contribution of natural abundance variation. *Am. J. Physiol.* **270**, E164–E169.

Rutishauser IHE, Wheeler CE, Conn JA & O'Dea K (1994): Food and nutrient intake in a randomly selected sample of adults: demographic and temporal influences on energy and nutrient intake. *Aus. J. Nutr. Diet.* **51**, 157–166.

Schoeller DA & van Santen E (1982): Measurement of energy expenditure in humans by doubly labeled water method. *Am. J. Physiol.* **53**, 955–959.

Schofield W, Schofield C & James WPT (1985): Basal metabolic rate—review and prediction, together with an annotated bibliography of source material. *Hum. Nutr: Clin. Nutr.* **39C**, Suppl. 1.

Stephens AM & Cummings JH (1979): The influence of dietary fibre on faecal nitrogen excretion in man. *Proc. Nutr. Soc.* **38**, 141A.

Wiles SJ, Nettleon PA, Black AE & Paul AA (1980): The nutrient composition of some cooked dishes eaten in Britain: a supplementary food composition table. *J. Hum. Nutr.* **34**, 241–248.