

Iodine intake and iodine deficiency in vegans as assessed by the duplicate-portion technique and urinary iodine excretion

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I intake and I deficiency were investigated in thirty vegans (eleven males and nineteen females) consuming their habitual diet. I intake was estimated using the chemical analysis of 4 d weighed duplicate diet collections. The probability of I-deficiency disorders (IDD) was judged from the measurement of urinary I excretion in 24 h urine specimens during the 4 d. There was wide variation in I intake. Mean I intake in males was lower than the reference nutrient intake (RNI; Department of Health, 1991) and mean intake in females was above the RNI, although 36 % males and 63 % females had I intakes below the lower RNI. Mean I intake in subjects who consumed seaweed (*n* 3) was in excess of the RNI, and approached the provisional maximum tolerable daily intake (World Health Organization/Food and Agriculture Organization Joint Expert Committee on Food Additives, 1989). The probability of IDD in the group investigated was moderate to severe: three of five subgroups were classified as moderate and two subgroups were classified as severe IDD possibility. The findings highlight that vegans are an 'at risk' group for I deficiency. The I status of vegans and the subclinical effects of low I intakes and infrequent high I intakes on thyroid function in this group should be further studied. Our work has also raised the question of adequate I intakes in groups where cow's milk is not consumed, and has exposed a need for more research in this area.

Vegans: Iodine: Nutrient intake

I is an important trace element required for normal growth and development, both physical and mental, and is an essential constituent of the thyroid hormones. When physiological requirements of I are not met, a series of functional and developmental abnormalities occur, including those of the thyroid gland (Delange, 1994). The effects of I deficiency, denoted by the term 'I-deficiency disorders' (IDD), are now widely recognized as a major public health problem and a significant problem in 118 countries worldwide (World Health Organization/United Nations Children's Fund/International Council for the Control of Iodine Deficiency Disorders, 1993).

In the UK, the main sources of I in an average diet are milk and milk products, accounting for 35 % of I intake, and fish is a rich natural source, although it provides less than 10 % of I intake due to low consumption (Lee *et al.* 1994). The I content of the average omnivorous diet is adequate (Gregory *et al.* 1990); however, there are certain groups of the population who may be at risk of low intakes of dietary I, and vegans (a group of strict vegetarians living on plant foods only), have been considered a potentially 'at risk' group. The acceptance of vegan diets is increasing and it is

estimated that approximately 250,000 adults in the UK are adopting this diet (The Realeat Survey, 1997). Various nutrient deficiencies associated with the vegan diet have been thoroughly investigated, although only four studies have included an assessment of I intake (Abdulla *et al.* 1981; Key *et al.* 1992; Draper *et al.* 1993; Rauma *et al.* 1994). Furthermore, restrictions within the study populations and methodologies used raise questions about the accuracy of the findings on I intakes of this group.

In view of this, a cross-sectional study was undertaken of the diet of adult vegans in London and the surrounding counties. The object of the study was to assess the I intake of adult vegans consuming their habitual diet and also to measure concurrently the probability of I deficiency.

Methods

Subjects

A group of thirty-nine 'healthy' vegans was recruited between July 1995 and October 1995 through the Vegan Society and were volunteers from our preliminary research

Abbreviations: IDD, I-deficiency disorders; LRNI, lower reference nutrient intake; PMTDI, provisional maximum tolerable daily intake; RNI, reference nutrient intake.

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in this area (Lightowler & Davies, 1996). Suitability of potential subjects was assessed according to specific selection criteria. Subjects were required to be at least 16 years of age, have a BMI between 18–28 kg/m², give written informed consent to participate and to notify their general practitioner as to their participation, and be resident within London or the south-east of England. Subjects were excluded from the study if they smoked on a regular basis and their alcohol consumption was in excess of the weekly recommended units (a maximum of 28 units for men and 21 units for women). Subjects were also excluded if they had been hospitalized during the last 3 months or subjected to general anaesthetic, were diagnosed as having a health disorder, and, in the case of females, if they were pregnant or lactating. This assessment was undertaken at the initial visit to each subject by way of a screening questionnaire. In addition, height and weight measurements were taken, using the Leicester Height Measure (2070 mm × 10 mm; Child Growth Foundation, London, UK) and Seca dial personal scales (150 kg × 500 g; Seca Ltd., Birmingham, UK) respectively, to calculate their BMI.

Measurement of iodine intake

I intake was measured over four consecutive days, and each day was defined as starting from midnight and continuing through until the subsequent midnight. This 4 d study period was considered adequate, as it has been suggested that a 3 d record is sufficient to determine differences between groups of individuals (Bingham, 1987). One weekend day was included to incorporate fluctuations in dietary patterns from weekdays to weekends. All subjects were asked to collect duplicate portions of everything that they ate and drank (including water) during the 4 d study period. Direct chemical analysis of foods or diets, in particular the duplicate-portion technique, has been considered the best method for the assessment of trace element intake (Abdulla *et al.* 1989; West & van Staveren, 1995). A 4 d weighed dietary record was used concurrently, as there is evidence that unweighed duplicate collections of food are incomplete (Stockley, 1985), and it was essential that each subject supplied an exact duplicate.

The weights from the duplicate diets and those reported were compared. It has been suggested that if the difference between the two total amounts exceeds 20 g, the reason for the discrepancy must be found and corrected (Bingham *et al.* 1988). However, in our study, as the total volume of duplicate diets collected over a 4 d period was great, it was considered that an arbitrary maximum of 10% difference was appropriate.

The measurement of urinary N is considered a useful method of validating estimates of dietary intake (Bingham *et al.* 1995). Due to constraints within this study, such a method was found not to be feasible, thus the problem of the representativeness of the duplicate diets was considered in the interpretation of the results.

Subjects were provided with a dietary collection kit which included a diet-record diary, large strong bags for food collection, leak-proof plastic bottles for the collection of drink, a digital readout balance (Soehnle, Switzerland;

1 kg × 1 g), ice packs and a cooled insulated bag. The procedure for weighing and collecting duplicate portions of food and drink was demonstrated. Each subject was also instructed to keep a written weighed record of everything they ate and drank in the diet-record diary. Recipe sheets were supplied for recording ingredients, cooking method and weight of the portion eaten. Subjects were also encouraged to collect labels and packaging of foods consumed.

Duplicate diets were kept, either in a refrigerator or in the cooled insulated bag, until they were collected. Duplicate meals from the first 2 d were collected half way through the investigation and stored at approximately 4°; the remaining duplicate meals were collected at the end of the 4 d period, along with the diet-record diary. The diary was checked in the presence of the subject to ensure that all the necessary detail had been provided. The weight of the duplicate diet was recorded and compared with the corresponding weight from the diet-record diary. The duplicate meals from the 4 d were pooled and homogenized; distilled water was added to two pooled samples, as both were too dry for homogenization, and the weight of the water recorded. Subsamples, weighing 200 g, were extracted into plastic containers and stored at –21° until analysed.

Measurement of iodine deficiency

Urinary I excretion is currently the most used biochemical marker of I deficiency (Dunn *et al.* 1993a) and, on a population level, used to judge the probability of IDD. A 24 h urine collection has been considered the most reliable specimen for testing urinary I levels (Dunn *et al.* 1993b), thus subjects were asked to collect all urine passed during the 4 d study period.

Inclusion of a method to validate the completeness of 24 h urine collections was considered, although the use of markers, such as 4-aminobenzoic acid (Bingham & Cummings, 1983), was not employed in the present study. Many vegans do not take medications or dietary supplements, therefore it was judged to be unethical to ask them to take markers. Additionally, it was not known whether the coating on such markers would be suitable for vegan consumption. Each subject was asked to keep a diary whereby they measured the volume of urine and time of passing. The volumes of urine collected were compared with those reported and an arbitrary maximum limit was set at 10% difference between the two volumes.

Subjects were provided with a urine collection kit which included a urine-record diary, a plastic graduated (ml) measuring jug, leak-proof plastic bottles, ice packs and a cooled insulated bag. All equipment in contact with the urine was labelled with distinguishable biohazard tape. Subjects were comprehensively instructed on the procedure for the collection of urine and the recording of volume and time in the urine-record diary. The urine was kept in the cooled insulated bag with the ice packs until it was collected, every other day. The urine was stored at approximately 4° until all collections were completed and collected, along with the urine-record diary. The volume of urine was measured and compared with the corresponding volume recorded in the diary. The urine from the 4 d period was pooled and thoroughly mixed under strict laboratory

conditions. Subsamples of 15 ml were transferred to sterile vials and stored at -21° until analysed.

Analytical methods

The duplicate-portion samples were analysed by the Laboratory of the Government Chemist. The method employed for the determination of I content was a standard semi-automatic method based on the catalytic destruction of thiocyanate by nitrite in the presence of iodide, and had a precision of 10% (Moxon & Dixon, 1980). The limit of detection set by the Laboratory was $<25 \mu\text{g I/kg food}$. The I values were given per kg food and these were then adjusted to represent an average daily I intake.

The measurement of I in the urine, carried out by one of the investigators (H. J. L.), was based on the Sandell-Kolthoff reaction (Sandell & Kolthoff, 1937). The method involved the digestion of urine with a chloric acid solution under mild conditions. The detection of I was carried out manually using ceric ammonium sulphate with ferroin as an indicator, and the colour change was subsequently timed with a stopwatch. A standard curve was constructed by plotting the I concentration of each standard *v.* the time elapsed to the colour change, and the urinary I concentration ($\mu\text{g/dl}$) of each urine sample was derived from the corresponding I concentration on the curve. The precision of the method used was good (Dunn *et al.* 1993*b*). All reagents used were analytical grade and all analyses were performed in duplicate.

The probability of IDD was judged according to the World Health Organization (1994) criteria for the assessment of the severity of IDD.

Statistical analysis

Statistical analysis was carried out using SPSS 6.1 (SPSS, Chicago, IL, USA, 1994). Between-group comparisons were made using ANOVA, and comparisons between I intakes without and with dietary supplements by paired *t* test. Pearson's correlation coefficient was used to assess associations between I intake and urinary I levels with various factors such as age, geographical location and BMI. I intakes were compared with data from previous vegan studies and a nationwide survey of UK adults (Gregory *et al.* 1990). Statistical significance was set at $P < 0.05$.

Results

Study population

Of the thirty-nine subjects recruited, thirty successfully completed the study. One male subject and five female subjects withdrew from the study, the main reason being the high level of cooperation and commitment that they were asked to provide. Data supplied by a further three subjects (one male and two females) were excluded due to incomplete collections of duplicate diets and urine.

Table 1 shows that the male and female vegans were similar in age, in their mean BMI (which were significantly lower ($P < 0.01$ and $P < 0.001$ respectively) than the average for the UK population; Gregory *et al.* 1990), and in the

Table 1. Characteristics of vegan subjects
(Mean values and standard deviations)

	Male (<i>n</i> 11)		Female (<i>n</i> 19)	
	Mean	SD	Mean	SD
Age (years)	40.2	7.7	38.4	14.8
Height (m)	1.79	0.1	1.63	0.1
Weight (kg)	70.5	12.4	57.2	9.5
BMI	22.0**	3.0	21.5***	3.1
Period on vegan diet (% life)	25	9.9	24	16.4
Weekly alcohol intake (units)	14.2	6.5	7.1	8.4

Mean values were significantly lower than those for the corresponding (male or female) UK population: ** $P < 0.01$, *** $P < 0.001$.

percentage of life on a vegan diet. The mean alcohol intake was higher in males than in females ($P = 0.082$). Two subjects (one male and one female) were occasional smokers and smoked less than two cigarettes per week. Specific diets were followed by six participants and included wheat-free, soya-free, and towards a fruitarian diet. A total of twenty-one different supplements, of which three were identified as containing I, were taken over the study period by five (45%) males and seven (37%) females, and three female subjects were taking medication (the contraceptive pill and a fibre preparation, which were not known to interfere with I metabolism or thyroid function). One female vegan had previously been diagnosed with hyperthyroidism and had been successfully treated using homeopathic methods.

Iodine intake: dietary sources

The mean weight of the duplicate diets was lower than that reported ($P = 0.415$); the mean percentage difference in the total weight of duplicate diets and recorded diets was 6 (SD 6).

Table 2 shows the I intakes of the subjects. The analysis of the duplicate diets indicated a wide variation in the daily I intake (<25 – $1467 \mu\text{g/kg food}$), and the upper end of the range was attributed to the group of subjects who consumed seaweed. Males had a lower I intake from food compared with females (138 (SD 149) and 187 (SD 346) μg respectively; $P = 0.668$). The mean daily I intakes from food for male and female vegans were lower than the average I intakes in the UK (Gregory *et al.* 1990), but were higher than those found in previous vegan studies.

The mean I intake of the group of male vegans was just below the reference nutrient intake (RNI) of $140 \mu\text{g/d}$ (Department of Health, 1991) and the mean intake in the female subjects was above the RNI (Table 2). Within these groups, a higher percentage of females (63; *n* 12) than males (36; *n* 4) had I intakes below the LRNI of $70 \mu\text{g/d}$ (Department of Health, 1991).

There was no association between I intakes and sex, age, geographical location, BMI classification and percentage of life on a vegan diet.

The I intake of the three subjects who ate seaweed was significantly higher ($P < 0.001$) than the intake of subjects who did not consume this food. The mean I intake in subjects who consumed seaweed was over six times the RNI;

Table 2. Mean iodine intake ($\mu\text{g}/\text{d}$) from food and iodine-containing supplements and percentage contribution to reference nutrient intake (RNI; Department of Health, 1991) for vegan subjects \ddagger (Mean values and standard deviations)

Subjects	I intake			% RNI
	Mean	SD	Range	
Total (n 30)	169	291	(25–1467)	121
Male (n 11)	137	149	(25–521)	98
Female (n 19)	187	346	(25–1467)	134
Consuming seaweed (n 3)	866 $\dagger\dagger\dagger$	523	(521–1467)	619
Taking I-containing supplements (n 5)				
Before supplements	97	77	(25–211)	69
After supplements	151*	76	(67–246)	108
Others \S (n 22)	87	95	(25–352)	62

The mean I intake after supplements was significantly different from that before supplements: * $P < 0.05$.

Mean I intake was significantly higher than that of other subjects: $\dagger\dagger\dagger P < 0.001$.

\ddagger For details of subjects and procedures, see pp. 529–531.

\S Those who did not consume seaweed or take I-containing supplements.

conversely, the intake in the group of subjects who did not eat seaweed or take I-containing supplements (n 22) was below the RNI (Table 2). Moreover, within this latter group, almost two-thirds had intakes below the LRNI.

Iodine intake: dietary supplements

Five subjects took dietary supplements which contained I during the 4 d study period, and the I intake from these was minimal. Before the addition of supplements, the mean I intake from food was below the RNI (Table 2). There was a significant difference ($P < 0.05$) in the mean daily I intake before and after dietary supplement usage. The addition of I-containing supplements increased the mean I intake above the RNI, although the intake in one subject remained below the LRNI.

The mean contribution to I from the dietary supplements taken, estimated according to the manufacturers' declarations on the packaging, was 54 (SD 39) μg , thus the subjects were adding I to their diets at, on average, 39 % of the RNI.

Urinary iodine excretion

The mean volume of urine was lower than that reported ($P = 0.682$); the mean percentage difference in the total volume of urine collected and the recorded volume was 5 (SD 4).

The mean urinary I concentration per litre urine was lower in males than in females (24.2 (SD 15) and 34.0 (SD 8) μg respectively; $P = 0.395$); the daily urinary I excretion was estimated to be 48.4 (SD 41) μg in males and 71.7 (SD 115) μg in females (Fig. 1). The mean daily urinary I excretion was highest in subjects who consumed seaweed and those who took I-containing dietary supplements. The mean urinary I excretion in I supplement-users was significantly higher ($P < 0.05$) than the mean excretion found in subjects who did not take such preparations or consume seaweed.

Iodine intake and urinary iodine excretion

Fig. 2 shows the dietary I intake and urinary I excretion of the subjects. With the exception of the group taking

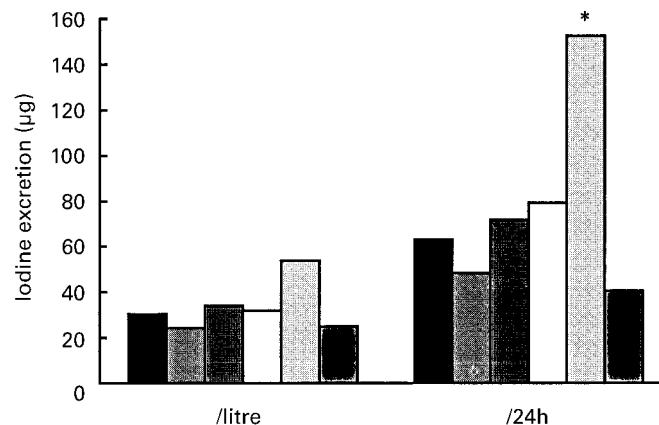


Fig. 1. Urinary iodine excretion in vegan subjects: total (■); male (▨); female (▩); consuming seaweed (□); taking I-containing supplements (▤); others (those who did not consume seaweed or take I-containing supplements) (▦). For details of subjects and procedures, see pp. 529–531. Mean urinary I excretion of subjects taking I-containing supplements was significantly different from that of the other subjects: * $P < 0.05$.

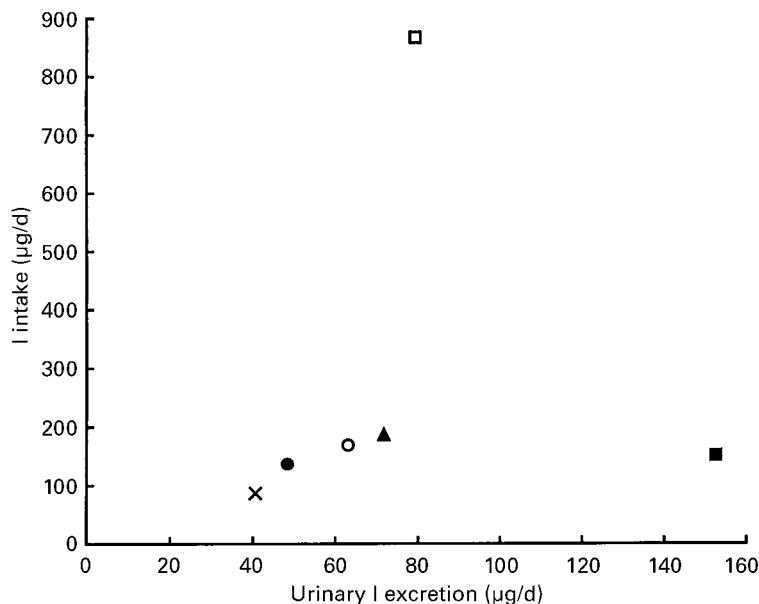


Fig. 2. Iodine intake and urinary iodine excretion in vegan subjects: total (n 30; ○), male (n 11; ●), female (n 19; ▲), consuming seaweed (n 3; □), taking I-containing supplements (n 5; ■), others, i.e. those who did not consume seaweed or take I-containing supplements (n 22; ×). For details of subjects and procedures, see pp. 529–531.

Table 3. Median urinary iodine ($\mu\text{g/l}$) and iodine-deficiency disorder probability for vegan subjects*

Subjects	Median urinary I ($\mu\text{g/l}$)	Probability of IDD
Total (n 30)	20.2	Moderate
Male (n 11)	16.8	Severe
Female (n 19)	20.5	Moderate
Consuming seaweed (n 3)	37.8	Moderate
Taking I-containing supplements (n 5)	36.9	Moderate
Others † (n 22)	17.7	Severe

* For details of subjects and procedures, see pp. 529–531.

† Those who did not consume seaweed or take I-containing supplements.

I-containing supplements, mean daily I excretion was not commensurate to mean daily I intake. The relationship between I intake and excretion in groups of total, male, female and other subjects was consistent.

Iodine deficiency

According to the World Health Organization (1994) criteria for the assessment of the severity of IDD, the probability of IDD in the group of vegans as a whole was moderate (median value between 20 and 49 μg I/litre urine; Table 3). Similarly, the likelihood of I deficiency in groups of female subjects, seaweed consumers and subjects taking I-containing dietary supplements was moderate. The probability of IDD in male subjects and those who did not consume seaweed or take I-containing supplements was severe (median value < 20 μg I/litre urine).

Discussion

It is widely accepted that dietary I is essential for thyroid function, with both deficient and excessive intakes having

serious repercussions. The findings from our study reveal the extremities of low and high I intakes in groups of vegans. The high intakes approached the provisional maximum tolerable daily intake (PMTDI; World Health Organization/Food and Agriculture Organization Joint Expert Committee on Food Additives, 1989) and were due to the consumption of seaweed. Our findings therefore highlight the importance of addressing the issue of I in the vegan diet.

While the mean I intake in the groups of vegans do not substantiate the suggestion by Draper *et al.* (1993) that vegans could be at risk of low intakes of dietary I, the wide variations in I intake indicates possible low intakes. In particular, the lower end of the range of I intakes in males, females, those taking dietary supplements, and 'other' subjects suggests very low intakes. The impact of a diet deficient in I on function and development is well documented; however, there is a lack of research on the subclinical effects of low I intakes in vegans. As low intakes of I might be expected to affect the size, nodularity and function of the thyroid gland, further work is now needed to assess such effects in vegans.

Although it has been suggested that environmental goitrogens (compounds which may enhance the effect of I

deficiency and produce deleterious effects in the thyroid gland) may normally be ineffective when low in concentration (Gaitan, 1980), a vegan diet is likely to include more foods possessing goitrogenic properties (e.g. brassicas), compared with an omnivorous diet, and this may affect I metabolism.

It has been reported that less than 1% of males and 3% of females in the UK have I intakes below the LRNI (Ministry of Agriculture, Fisheries and Food, 1994); thus the high percentage of male and female vegans with intakes of I below the LRNI is alarming. The classification of males and females according to their individual intake in this respect was reliable as, although a 7 d period is usually the minimum for measurement of individual intake (Bingham, 1987), it has been shown that nutrient intakes from 3 d or 4 d periods are similar to those for 7 d (Fehily, 1983).

The PMTDI for I is 1000 µg (World Health Organization/Food and Agriculture Organization Joint Expert Committee on Food Additives, 1989). It would appear from our results that the influence of seaweed on I intakes may be considered adverse in some situations, as the intakes of vegans who ate this food were approaching or exceeded the PMTDI. Excess I intake has well-established effects on thyroid status, and can result in functional impairment of, and tissue damage to, the thyroid gland. Although edible seaweed contains very high levels of I, the proportion of vegans who eat this food, the actual amount consumed and the frequency of consumption are low (Lightowler & Davies, 1996). Thus, subclinical effects of high but infrequent I intakes in vegans need to be addressed. Furthermore, as I is not stored in the body, the extent of the carry-over from high intakes is unclear.

The suggestion that vegans are not taking I from dietary supplements in amounts sufficient to raise intakes to the RNI (Draper *et al.* 1993) was substantiated by our results. However, there is a potential danger of kelp tablets increasing intakes of this trace element to the PMTDI, especially if the manufacturers' recommended doses are adhered to. The use of I-containing supplements as a whole may be considered unsatisfactory due to the expense of the product and the uncertainty and variability of the I content of the supplement (Lee *et al.* 1994). A more satisfactory method of increasing the I intake of vegans to an adequate level needs to be considered. Although in many developing countries iodized salt is considered a good medium for I prophylaxis, encouragement to use this commodity as a vehicle for increasing I intakes in vegans may not be acceptable in the interest of recent reports (Department of Health, 1994). In the UK, iodized salt adds little to I intake through manufactured foods, the kitchen or at the table, and such a contribution would be small for vegans.

It would appear from the results of the present study that the urinary I level of the groups of vegans investigated was low. With the exception of the group of subjects who took I-containing supplements, I excretion was not commensurate with I intake, thus classification of moderate IDD probability did not equal the I intake. This was attributed to a number of different factors. Obtaining urinary I that truly reflects I intake is difficult (Dunn *et al.*

1993b). Malvaux *et al.* (1969) have suggested that I output only equals I input over a relatively long period of time, therefore, the 4 d period in the present study may have been too short, although the feasibility of collecting urine for a longer period of time is questionable. Furthermore, previous research indicates that some seaweeds contain much indigestible I (Katamine *et al.* 1987), thus I excretion in this particular group may not reflect I intake.

Comparison of urinary I levels in vegans with those of the UK population is difficult as there is limited information on urinary I excretion in the UK. Compared with studies conducted over a decade ago, the daily urinary excretion of I found in our subjects was significantly lower ($P < 0.01$) than the daily urinary I excretion reported by Broadhead *et al.* (1965), and lower than that recorded by Nelson *et al.* (1987; $P = 0.462$).

The finding that the probability of IDD in the group of vegans investigated ranged from moderate to severe is of some concern. Other biochemical indicators and clinical indicators, such as measurement of thyroid-stimulating hormone and thyroid size, are necessary to determine the I status of vegans.

The constraints within the present study made it unfeasible to undertake objective validation methods, thus the validity of the data derived from the duplicate diets and 24 h urine collections should be addressed. While the duplicate-portion technique was considered the most accurate method for the estimation of I intake in vegans, the possibility of duplicate diets being atypical may occur. Similarly, the absence of a measure to verify the completeness of the 24 h urine collections may question the accuracy of the results.

The evidence of the difference between weights from the duplicate diets and those reported, and the volumes of urine and those reported, suggests that both collections were virtually complete. While this does not tell us about the validity of the data, the fact that weights and volumes agreed between collections and records indicates their accuracy.

In view of the fact that cow's milk and milk products are the main sources of I in the average UK diet (Lee *et al.* 1994), when cow's milk is replaced (e.g. in individuals who have allergies and intolerance to cow's milk), the question of adequacy with regard to I intake is raised. Conversely, as consumption of certain seaweeds may increase intakes of I to the PMTDI, the question of excessive I intakes in individuals who eat seaweed in the context of an omnivorous diet and those who follow a macrobiotic diet, which advocates the consumption of seaweed as well as sea fish, is also raised.

In conclusion, our study has highlighted that vegans are an 'at risk' group for I deficiency. While the use of seaweed and I-containing dietary supplements may increase I intakes, possibly to the PMTDI, low consumption and usage means that the probability of IDD remains moderate. The subclinical effects of both low and high but infrequent intakes of I are now required to measure the I status of vegans. Furthermore, a more satisfactory method of increasing I intake to adequate levels needs to be sought.

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