THE OFFICIAL JOURNAL OF THE BRITISH DIETETIC ASSOCIATION

Journal of Human Nutrition and Dietetics

CLINICAL NUTRITION

Nutritional inadequacies of the gluten-free diet in both recently-diagnosed and long-term patients with coeliac disease

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Keywords
coeliac disease, dietary assessment, gluten-free diet, nutritional adequacy.

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How to cite this article
Shepherd S.J. & Gibson P.R. (2013) Nutritional inadequacies of the gluten-free diet in both recently-diagnosed and long-term patients with coeliac disease. *J Hum Nutr Diet*. **26**, 349–358
doi:10.1111/jhn.12018

Abstract

Background: Life-long gluten-free diet (GFD) is the only recognised treatment for coeliac disease (CD). The present study aimed to determine the nutritional adequacy of the 'no detectable gluten' diet.
Methods: Seven-day prospective food intake was assessed in 55 patients who were adherent to a GFD for more than 2 years and in 50 newly-diagnosed age- and sex-matched patients (18–71 years, 24% male) studied prospectively over 12 months on GFD. Historical precoeliac intake was also assessed in the latter group. Intake was compared with Australian Nutritional Recommendations and the Australian population data.
Results: Nutritional intake was similar between groups. Of macronutrients, only starch intake fell over 12 months (26% to 23%, $P = 0.04$). Fibre intake was inadequate for all except in diet-experienced men. More than one in 10 of both newly-diagnosed and experienced women had inadequate thiamin, folate, vitamin A, magnesium, calcium and iron intakes. More than one in 10 newly-diagnosed men had inadequate thiamin, folate, magnesium, calcium and zinc intakes. Inadequate intake did not relate to nutrient density of the GFD. Inadequacies of folate, calcium, iron and zinc occurred more frequently than in the Australian population. The frequency of inadequacies was similar pre- and post-diagnosis, except for thiamin and vitamin A, where inadequacies were more common after GFD implementation.
Conclusions: Dietary intake patterns at 12 months on a GFD are similar to longer-term intake. Dietary inadequacies are common and may relate to habitual poor food choices in addition to inherent deficiencies in the GFD. Dietary education should also address the achievement of adequate micronutrient intake. Fortification of GF foods also need to be considered.

Introduction

Coeliac disease (CD) is unique amongst chronic disorders in that diet is the only recognised treatment. It is expected that, after the initiation of a gluten-free diet (GFD), the enteropathy will improve (Fasano & Catassi, 2001; Williamson & Marsh, 2002; Pietzak, 2005) and the restoration of absorptive surface area will enable the normal absorption of nutrients to occur. Strict compliance to a GFD is considered to be an essential part of patient management and is advocated in all patients with CD (Hill *et al.*, 2005). The GFD taught in Australia is a 'no detectable gluten' standard (Shepherd & Gibson, 2006), comprising of foods that have a gluten content of <3 p.p.m. (i.e. gluten not detectable in currently available assays; The Coeliac Society of Australia, 2011).

Any restrictive diet is inherently at risk of nutritional inadequacy (Thompson *et al.*, 2005). Although nutritional targets from the foods consumed by the Australian population have been set by governmental bodies [Commonwealth Department of Health & Ageing, 2006; National Health & Medical Research Council (NHMRC), 1991], no assessment has been made regarding the adequacy of the GFD, apart from a preliminary report of

fibre intake in 40 patients (Tatnell *et al.*, 1985). Previous studies in other countries have generally (Bode *et al.*, 1991; McFarlane *et al.*, 1995; Thompson, 1999, 2000; Ciclitira *et al.*, 2001; Grehn *et al.*, 2001; Hallert *et al.*, 2002; Thompson, 2005; Zarkadas & Case, 2005; Hopman *et al.*, 2006; Kinsey, 2008; Niewinski, 2008; Lee *et al.*, 2009; Wild *et al.*, 2010) but not always (Robins *et al.*, 2008) found the GFD to be nutritionally inadequate. For health professionals educating patients with CD on the GFD, it is vital to know whether people can meet nutritional targets with a GFD, how that ability compares with the general population, and what implication any inadequacies may have on the health of people with CD.

The present study aimed to examine the nutritional adequacy of the 'no detectable gluten' diet in people with CD. Accordingly, three strategies were employed. First, the intake of nutrients by patients with at least 2 years experience of the GFD was examined. Second, the nutrient intake of a cohort of patients recently educated in the GFD by a dietitian with expertise in CD was assessed and compared with that of experienced patients. Finally, the effect of a diagnosis of CD and change to a GFD on nutritional adequacy of the diet was examined.

Materials and methods

Patients

Two groups of patients were recruited: (i) 57 newly-diagnosed, untreated patients who were consecutively referred to a single dietetic service, from gastroenterologists and general practitioners, or the Coeliac Clinic at Box Hill Hospital; and (ii) 60 patients with long-term treated CD who were recruited from private practice, public hospital clinics and advertisements at the Coeliac Society of Victoria. They had all been apparently compliant with the GFD for a median of 6 (range 2–33) years based on dietary history and this was supported by the absence of coeliac antibodies (if present at diagnosis), or having a healed duodenal biopsy if previous coeliac serology was unavailable. These patients were age- and sex-matched to the newly-diagnosed cohort.

The diagnosis of CD was made in all patients according to European Society for Paediatric Gastroenterology & Nutrition (ESPGAN) criteria (ESPGAN, 1990). In addition, two patients with the combination of Marsh I lesions (Marsh, 1992) and positive tissue transglutaminase antibodies were included. All had human leukocyte antigen DQ2 and/or DQ8 haplotypes. No patients had comorbidities such as inflammatory bowel disease or diabetes, or a psychiatric disorder or intellectual disability that would make it unlikely that they could complete the study requirements.

Protocol

All patients were assessed by an experienced Accredited Practising Dietitian. Patients underwent a structured interview in which their symptoms, demographic information, data regarding anthropometry, previous dietary patterns, and details of the referring and other relevant medical practitioners were recorded. For newly-diagnosed patients, a complete dietary history was taken in which the typical daily food intake before the diagnosis of CD was quantified by direct questioning during interview (Biro *et al.*, 2002). Patients were then educated in a nutritionally adequate 'no detectable gluten' diet, which was recommended to be followed for life. Education included description of the five-food-group healthy-eating model, including recommended servings and attention to fibre and variety in the diet.

At the first interview, all patients were asked to keep a 7-day food record. Patients were provided with a recording diary card and instructions for its completion. They were asked to record the type and brand of food and how much was eaten or drunk using household measures on each day for the 7-day period before the review appointment. Measuring cups, spoons and reference diagrams were provided. Recorded information was checked at the consultation. The newly-diagnosed cohort of patients was reviewed approximately 3-monthly and, at the end of 12 months, was asked to fill out another prospective 7-day food diary.

Adherence to the GFD diet was evaluated in detail at every interview by direct questions about any gluten consumed, either accidentally or intentionally in the time since their last review, by specific questioning and, if available, by the 7-day food diary entries.

Biochemical and haematological indices were measured in peripheral blood samples taken from all patients at entry to the studies and, additionally, at 3, 6 and 12 months for the newly-diagnosed cohort. These included a complete blood count, electrolytes, renal function, liver function tests and iron studies, as well as serum folate, vitamin B_{12}, zinc, vitamin D, magnesium, calcium and phosphate, using routine methodologies. Patients also had a repeat and histopathological examination of duodenal biopsies or close to 12 months after the initial assessment.

The protocol was approved by Eastern Health Research and Ethics Committee and Monash University Standing Committee on Ethics in Research Involving Humans. All participants provided theri written, informed consent form before entering the study.

Analysis of food intake

Results from the 7-day food record were analysed using FOODWORKS™ food analysis software (Xyris Software, Highgate Hill, Queensland, Australia), incorporating

nutrient tables for use in Australia [The authors/owners of Nuttab 95 and Ausnut 1999-2004 are Food Standards Australia and New Zealand (FSANZ)].

The nutritional profile of specialist gluten-free foods that were not listed within the FOODWORKS™ software was constructed from ingredient information from the food manufacturer. Dry packaged mixes (such as bread and mixes) were prepared by a qualified chef, employed by an educational institution, and made in accordance with standard packet instructions in a registered industrial kitchen. Nutritional compositional data of constructed foods were entered for their consumed edible state (i.e. as edible portions such as cooked pasta). The nutritional profile of freshly prepared foods and beverages consumed by patients were constructed from ingredient information provided by the patient.

Adequate intake of micronutrients (vitamins and minerals) was established by comparison of measured intake against nutrient reference values (NRVs) (Commonwealth Department of Health & Ageing, 2006), comprising the estimated average requirement (EAR) or adequate intake (AI) where appropriate. Macro-nutritional adequacy (including fibre) was established by comparison against the NRVs. Comparison of intake with the general healthy population (control group) was made using results from the National Nutrition Survey (Australian Bureau of Statistics, 1999). The intake of nutrients from supplements was not included in the analyses.

Estimated energy expenditure for patients was calculated using the FOODWORKS^{TM} software formed from the basal metabolic rate using the Schofield equation (Schofield, 1985), from height and weight information entered, and with an activity factor applied. Activity levels were based on self-reported energy expenditure recorded at the time of recruitment into the study for diet-experienced patients and at the 12-month review for the newly-diagnosed group. Total estimated energy intake from the 7-day food diary was compared against estimated energy requirement (EER) (as described above). Nutrient density of individual diets was determined by dividing the recommended daily intake (RDI) for each nutrient by the estimated energy requirement.

Statistical analysis

Statistical analysis was performed using GRAPHPAD PRISM, version 4.00 (GraphPad Software, San Diego, CA, USA) and STATA, version 8.2 (Stata Corporation, College Station, TX, USA). Comparison between groups was made with unpaired *t*-tests and Welch's correction. Comparison with the population was conducted using McNemar's test. Proportions were compared using Fisher's exact or chi-squared tests. Pearson's or Spearman's correlations were used for parametric or nonparametric data, respectively. Normally distributed data were expressed as the mean (SD). $P \leq 0.05$ was considered statistically significant.

Results

Patients

Only patients with complete data sets were included in the analysis. Fifty of 57 newly-diagnosed patients were assessed. All patients were considered adherent with their GFDs. Median age was 44 (range 18–71) years and 33 (71%) were female. Median body mass index (BMI) of women was 22.9 (19.1–40.2) kg m^{-2} initially and 24.4 (19.6–40.6) kg m^{-2} at 12 months. Median BMI of men was 23.4 (18.3–34.2) kg m^{-2} initially and 25.5 (20.0–36.9) kg m^{-2} at 12 months. Fifty-five of 60 patients experienced in the GFD were studied and were aged 43 (19–71) years with 44 (80%) being female. The age of diagnosis was 33 (1–61) years with the median time since diagnosis being 6 (2–33) years. Median BMI was 24.2 (16.0–37.7) kg m^{-2} for women and 25.0 (20.6–36.5) kg m^{-2} for men. There were no statistically significant differences in BMI between the newly-diagnosed patients at either diagnosis or 12 months and those of experienced patients.

Comparison of nutritonal intake of newly-diagnosed and diet-experienced patients

Under- and over-reporting was not evident in the patient group, as determined by a threshold ±20% of estimated individual energy requirement (Mela & Aaron, 1997). The intake of a wide range of nutrients by both cohorts, as calculated from prospective 7-day food diaries, is shown in Table 1 according to sex. The only differences were that men experienced with the GFD had lower intakes of saturated fat and carbohydrates than those who were newly-diagnosed ($P = 0.029$ and 0.001, respectively, unpaired *t*-test). All nutrients were consumed in greater quantities than the mean intake of the Australian population for both sexes (Australian Bureau of Statistics, 1995), except for thiamin in women ($P < 0.001$, one-sample *t*-test) with recently-diagnosed CD (Table 2). Mean intakes also exceeded population nutritional targets compared to EAR or AI for all nutrients except fibre in women in both cohorts and fibre for men and folate in women in those with newly-diagnosed CD (Table 1).

The proportions that individual macronutrients contributed to total energy intake were similar in both groups (Table 2) and for the Australian population (Australian Bureau of Statistics, 1999). The mean energy distributions for both groups fell within the Acceptable Macronutrient Distribution Range (AMDR) (Commonwealth Department of Health & Ageing, 2006) except for saturated fat, which was in excess of the recommendations in all groups.

The nutritional adequacy of the GFD was also compared with individual nutritional targets, according to Recommended Dietary Intakes (Commonwealth Department of Health & Ageing, 2006; Table 3). The proportions of patients and type of nutrients that were observed as inadequate were similar for both groups of patients at 12 months. The only

Table 1 Nutrient intakes of (i) patients with newly-diagnosed coeliac disease before commencing a gluten-free diet, as determined by detailed dietary history, and 12 months after the initiation of a gluten-free diet and (ii) diet-experienced patients, as determined by prospective 7-day food diary

	Nutrient	Newly-diagnosed prediagnosis	Newly-diagnosed at 12 months	Diet-experienced	Australian population (Australian Bureau of Statistics, 1999)	EAR or AI for ages 18–49 years (Commonwealth Department of Health and Ageing *et al.*, 2006)
Women	Energy (kJ)	8443 (1400)	7978 (1630)	8540 (1352)	7481[f]	NA
	Protein (g)	95.8 (16.9)	83.3 (18.8)[c]	89.2 (15.6)	73.9[f]	0.6 g kg^{-1} body weight
	Total fat (g)	66.8 (20.2)	69.7 (19.6)	72.7 (17.2)	67.6	NA
	Saturated fat (g)	26.9 (10.5)	27.9 (9.6)	27.9 (8.1)	26.7	NA
	Carbohydrate (g)	238 (47)	219 (50)[a]	236 (47.9)	211	NA
	Dietary fibre (g)	23.6 (6.1)	21.0 (6.4)[b]	22.0 (6.5)	20.3	25
	Thiamin (mg)	1.58 (0.57)	1.17 (0.50)[c]	1.25 (0.43)	1.4[g]	0.9
	Riboflavin (mg)	2.42 (0.79)	2.00 (0.61)[b]	1.25 (.0.43)	1.8	0.9
	Niacin equivalents (mg)	42.9 (12.8)	37.5 (0.6)[b]	41.1 (7.6)	34.1	11
	Vitamin C (mg)	152 (60)	146 (±63)	132 (55.3)	113[g]	30
	Total folate (μg)	337 (72)	299 (120)[a]	316 (97.5)	233[g]	320
	Total vitamin A equivalents (μg)	1362 (1306)	1284 (1180)	1013 (371)	1047	500
	Sodium (mg)	2821 (787)	2660 (1130)	2723 (1206)	NA	460
	Potassium (mg)	3037 (739)	3513 (924)	3634 (795)	2805[h]	2800
	Magnesium (mg)	333 (76)	345 (111)	378 (95.1)	283[g]	265
	Calcium (mg)	996 (347)	920 (297)	987 (282.2)	749[f]	840
	Phosphate (mg)	1479 (314)	1716 (492)	1633 (314)	1272[h]	580
	Iron (mg)	13.1 (10.8)	11.2 (4.0)[b]	11.7 (3.37)	11.9	8
	Zinc (mg)	11.6 (42.9)	11.2 (2.7)	11.98 (2.8)	9.7[g]	6.5
Men	Energy (kJ)	12196 (2615)	12321 (2675)	11291 (1863)	9238[g]	NA
	Protein (g)	114.9 (15.7)	123.4 (19.6)	98.8 (22.83)	91.2[h]	0.68 g kg^{-1} body weight
	Total fat (g)	101.4 (27.2)	113.8 (33.5)	67.9 (50.58)	82.8[g]	NA
	Saturated fat (g)	42.4 (17.9)	48.7 (±12.3)	34.7 (7.7)[d]	32.7[g]	NA
	Carbohydrate (g)	244 (64)	328 (75)	294 (72.3)[e]	255[g]	NA
	Dietary fibre (g)	31.2 (11.4)	28.1 (9.9)	30.2 (7.7)	23.1	30
	Thiamin (mg)	2.33 (0.87)	1.62 (0.61)	1.72 (0.55)	1.6	1.0
	Riboflavin (mg)	2.99 (0.87)	2.46 (0.66)	1.72 (0.55)	2.1	1.1
	Niacin equivalents (mg)	54.4 (8.1)	57.3 (11.8)	63.6 (13.8)	42.3	12
	Vitamin C (mg)	177 (84)	199 (113)	180 (72.7)	124[f]	30
	Total folate (μg)	460 (137)	410 (166)	403 (177.5)	269[g]	320
	Total vitamin A equivalents (μg)	1512 (532)	1251 (451)	1154 (430)	1177	625
	Sodium (mg)	3818 (1104)	3464 (723)	3239 (987)	NA	460
	Potassium (mg)	4088 (694)	4640 (991)	4812 (1092)	3258[g]	3800
	Magnesium (mg)	405 (86)	439 (128)	480 (125.7)	331[f]	350
	Calcium (mg)	1084 (329)	1153 (397)	909 (231.6)	846[f]	840
	Phosphate (mg)	1930 (210)	2127 (475)	2075 (372)	1520[h]	580
	Iron (mg)	17.1 (4.5)	14.4 (2.6)[a]	15.8 (2.7)	14.1	6
	Zinc (mg)	15.2 (2.2)	16.9 (2.7)	17.4 (3.83)	12.1[h]	12

Mean data from the Australian adult population and the estimated adult requirement or adequate intake are included for comparison.
[a]$P < 0.05$, [b]$P < 0.001$, [c]$P < 0.0001$; comparison between pre- and post-diets; unpaired *t*-test (Welch's correction).
[d]$P < 0.001$, [e]$P < 0.0001$; comparison between newly-diagnosed at 12 months and diet-experienced patients; unpaired *t*-test (Welch's correction).
[f]$P < 0.05$, [g]$P < 0.001$, [h]$P < 0.0001$; comparison 12 month diet versus Australian population mean (one-sample *t*-test).
AI, adequate intake; EAR, estimated adult requirement; NA, not available.

Table 2 Mean (SEM) contribution of macronutrients to energy intake of patients with newly-diagnosed coeliac disease before diagnosis and after 12 months on a gluten-free diet

Nutrient	Study population			Australian population (%)§	AMDR (%)
	Prediagnosis (%)†	12 months (%)‡	Diet-experienced (%)‡		
Protein (g)	19.7 (0.5)	18.3 (0.4)	18.5 (0.4)	17.0	15–25
Total fat (g)	30.1 (0.8)	34.2 (0.8)	32.5 (0.6)	32.4	20–35
Saturated fat (g)	12.1 (0.7)	13.9 (0.8)	12.5 (0.7)	12.7	8–10
Carbohydrates					
Total (g)	47.1 (0.7)	44.8 (0.8)	45.8 (0.7)	45.1	45–65
Sugars (g)	21.4 (0.8)	21.5 (0.6)	21.0 (0.7)	19.4	NA
Starch (g)	25.7* (0.7)	23.2 (0.8)*	24.8 (0.7)	25.7	NA
Alcohol (g)	3.1 (0.5)	2.6 (0.5)	3.3 (0.6)	4.8	NA

Data from the Australian population and the Acceptable Macronutrient Distribution Range are shown for comparison.
*$P = 0.04$, compared between pre- and post-diets; Mann–Whitney *U*-test.
†Data were obtained from diet history.
‡Data were obtained from 7-day food diaries.
§Data were obtained from the National Nutrition Survey 1995 (Australian Bureau of Statistics, 1999).
AMDR, Acceptable Macronutrient Distribution Range; NA, not available.

statistically significant difference observed between the two cohorts was inadequate magnesium ($P = 0.03$, Fisher's exact test) intake in women, and riboflavin ($P < 0.05$) and vitamin A ($P < 0.05$) in men with recently-diagnosed CD.

As shown in Table 3, inadequate intake of micronutrients that affected more than one in 10 patients were observed for fibre, thiamin, folate, magnesium and calcium in both sexes in both groups, for vitamin A and iron in women for both groups, for zinc in men in both groups, and for riboflavin and vitamin A in diet-experienced patients only.

In the newly-diagnosed patients, inadequate nutrient intake was associated with inadequate overall food intake (in relation to EER) for fibre, thiamin, calcium, magnesium and folate ($P < 0.05$ Fisher's exact test). Only for iron ($P = 0.23$) and vitamin A ($P = 1.0$) was inadequate intake independent of volume of food eaten. In the diet-experienced patients, inadequate intake of iron ($P = 0.39$, Fisher's exact test), folate ($P = 1.0$), vitamin A ($P = 0.57$), thiamin ($P = 1.0$) and fibre ($P = 1.0$) were all unrelated to inadequate food intake.

The majority of newly-diagnosed patients ate nutrient-dense diets, with comparative analysis between actual nutrient/MJ eaten and target nutrient/EER MJ showing that only five of 50 (10%) patients did not meet target nutrient density. This applied to four nutrients (fibre, vitamin A, calcium, zinc; and fibre, folate, calcium, iron) in two patients, two nutrients (fibre, folate; and thiamin, folate) in two patients, and one nutrient (fibre) in one.

Comparison of nutrient intake before and after institution of the gluten-free diet

Nutrient intakes before diagnosis (on a gluten-containing diet) in the newly-diagnosed cohort were evaluated by dietary history taken at the initial assessment and compared with those assessed by prospective food intake diaries. The results are shown in Table 1.

In women, mean intakes post-diagnosis were statistically significantly lower for protein (83 g versus 96 g), carbohydrate (219 g versus 238 g), fibre (21.0 g versus 23.6 g), thiamin (1.2 mg versus 1.6 mg), riboflavin (2.0 mg versus 2.4 mg), niacin (37.5 mg versus 42.9 mg), folate (299 μg versus 337 μg) and iron (11.2 mg versus 13.1 mg) after 12 months on the GFD (all $P < 0.05$, paired *t*-test). There was also a tendency for fat consumption to increase. In men, lower mean thiamin (1.6 mg versus 2.3 mg) and iron (14.4 mg versus 17.1 mg) intakes were observed at 12 months ($P < 0.05$) in contrast to the nonsignificant trend towards an increase in zinc intake (16.7 mg versus 15.2 mg). Changing to a GFD did not significantly increase the proportion who had inadequate fibre intake in both men, from 7/13 (54%) to 8/13 (62%), and women, from 21/33 (64%) to 25/33 (76%), ($P = 0.99$ and 0.42, respectively; Fisher's exact test). There were statistically significant increases in the proportions of inadequacies for the intake of vitamin A in women and thiamin for men and women (Table 3).

Discussion

The present study identified that a complex relationship existed between the dietary habits of the individual, the characteristics of the GFD and the nutritional adequacy of what is being consumed. Many of the inadequacies of dietary intake, such as a deficient intake of fibre and folate, may originate in the food choice of the individual, whereas some deficiencies of intake, such as thiamin, appear to be coeliac-specific.

Table 3 Proportion of patients who had inadequate mean dietary intakes in relation to recommended daily intakes

	Female				Male			
Nutrient	Prediagnosis (%)†	12 months (%)†	Diet-experienced	Australian population (%)‡	Prediagnosis†	12 months (%)†	Diet-experienced (%)	Australian population (%)†
Number	33	33	44		13	13	11	
Thiamin (mg)	**7 (21)**	**19 (58)****	**19 (43)**	0	0	**5 (38)***	**3 (27)**	0
Riboflavin (mg)	0	2 (6)	1 (6)	0	0	0	**2 (18)*****	0
Niacin equiv (mg)	0	0	0 (0)	0	0	0	0 (0)	0
Vitamin C (mg)	0	1 (3)	2 (5)	0	0	0	1 (9)	0
Folate (μg)	**28 (85)**	**31 (94)**	**34 (77)**	**42**	**5 (38)**	**7 (54)**	**8 (73)**	**23**
Vitamin A equivalents (μg)	1 (3)	**8 (24)***	**8 (33)**	0	1 (8)	0	**3 (27)*****	0
Magnesium (mg)	**13 (39)**	**17 (52)**	**11 (25)**	**33**	**9 (69)**	**6 (46)**	**4 (36)**	
Calcium (mg)	**21 (64)**	**21 (64)**	**27 (61)**	**25**	**6 (46)**	**7 (54)**	**9 (82)**	5
Phosphate (mg)	0	2 (6)	1 (2)	0	0	0	0 (0)	0
Iron (mg)	**28 (85)**	**25 (76)**	**31 (70)**	**34**	0	0	0 (0)	0
Zinc (mg)	0	2 (6)	4 (9)	**31**	**3 (23)**	**3 (23)**	**2 (18)**	0
Fibre (g)	**21 (64)**	**25 (76)**	**31 (70)**	19	**7 (54)**	**8 (62)**	**7 (64)**	14

Nutrients in which more than one in 10 patients had inadequate micronutrient intake are shown in bold. The proportion of the Australian population with inadequate intakes is also shown.

*Comparison between pre- and post-diets; $P < 0.05$; Fisher's exact test.

**Comparison between pre- and post-diets; $P < 0.001$; Fisher's exact test.

***Comparison between 12 months and diet-experienced patients; $P < 0.05$; unpaired *t*-test (Welch's correction).

†Newly-diagnosed coeliac disease patients before diagnosis and after 12 months on a gluten-free diet.

‡Data from the National Nutrition Survey 1995 (Australian Bureau of Statistics, 1999).

RDI, recommended daily intakes.

Best-practice methods were applied to obtain and analyse dietary data; however, they do have limitations. First, potential recording errors including inaccurate estimates of portions consumed and omission of foods (deliberate or unintentional) can result in an underestimation of nutritional intake. Behavioural changes altering intake have also been reported in patients who are keeping food records (Mela & Aaron, 1997). However, there is no assessment tool that is without limitation or specifically designed for the adult population with CD. Second, comparing the results from two different methods for the quantification of dietary intake introduces potential inaccuracies. The use of prospective food diary entries (after 12 months of GFD) and comprehensive dietary history (used to obtain prediagnosis data) was unavoidable because it would be unethical to request patients to continue on a gluten-containing diet and record intake in a prospective food diary after the diagnosis of CD. However, the accuracy of comprehensive dietary history has been validated (Van Staveren & Ocke, 1990). Third, it is possible that data entered for new products were associated with error because these relied upon information provided by food manufacturers. Finally, patient characteristics might introduce bias to the results. For the newly-diagnosed group, selection bias was minimised by recruiting patients who were consecutively referred; however, follow-up was more intense than usual as a result of their involvement in a prospective clinical study. Indeed, all patients were adherent to the diet. For the diet-experienced patients, the act of volunteering for the study and the prerequisite strict adherence to the GFD might be indicative of more motivated patients who may be more likely to adopt a more nutritious GFD than people not in the study. Data from both patient groups probably represent best-case scenarios. The observation that few differences in nutrient intake were observed between those experienced in the GFD, in whom gluten-free food habits have been formed over median 6 years of unsupervised free choice, and those who were taught the diet within a prospective study was reassuring with respect to these potentially confounding factors not having a significant impact upon the findings.

With such limitations in mind, the results gave clear indications of excesses and inadequacies. Nutritional adequacy data can be accurately and validly extrapolated from the data obtained in the present study because under- and over-reporting were not evident. Reported energy intake exceeded estimated energy expenditure for most patient groups. This is consistent with the weight gain observed in newly-diagnosed patients during the prospective follow-up as reported in the World Health Organization (2003); for example, the mean weight gain over 12 months was 2.7 kg in women and 3.6 kg in men, equating to an excess energy consumed per day of 250 kJ and 335 kJ, respectively. Saturated fat consumption was also well above the AMDR recommendation for patients in both cohorts. This is not a coeliac-specific phenomenon; it was similar to the intake of the Australian population and has been associated with chronic disease (Gross *et al.*, 2004). Because the dietary intake data were not analysed according to the actual foods consumed, sources of saturated fat were not identified.

Summary data did suggest that people eating a GFD in Australia generally achieve population (EAR) nutritional targets (Table 1). The exceptions are fibre and folate for women, although this is not different from the general Australian population. Interestingly, the majority met nutritional targets for nutrient density. By contrast, the major proportion of patients did not meet their RDI or AI requirements (Table 3). Therefore, it is questionable that nutrient density equates to sufficient daily intakes of RDI or AI.

The findings in both cohorts were highly consistent. Inadequacies could be classified into three groups. First, the inadequate intake of magnesium was the only nutrient that appeared to reflect that of the population in general. Although whole grain wheat is a good source of magnesium, the amount is minimal in refined wheat products commonly consumed in the community (Gross *et al.*, 2004). Other good sources of magnesium, such as leafy green vegetables, legumes, meat and seafood, are available to both gluten-free and gluten containing diets. This may explain why the trends are similar in both groups.

Second, inadequacies in fibre, folate, calcium, iron (women) and zinc (men) were frequently present before diagnosis by as much as 12 months on the GFD. The frequency of poor intake with untreated CD might be a manifestation of being unwell *per se*, although almost identical prevalence of such deficiencies were observed in patients who had been well on the GFD for at least 2 years. Such inadequacies may reflect the effect of deficiencies specific to gluten-free foods. There are reasons why the GFD might additionally compromise the adequate intake of some nutrients, such as folate, for example, because very few gluten-free breakfast cereals are fortified with folate compared to the common practice of fortification in wheat-based cereals [Food Standards Australia & New Zealand (FSANZ), 2008].

Third, inadequacies of the intake of thiamin and of vitamin A in women only were observed more commonly with the GFD than in the diet before diagnosis. The lack of availability of gluten-free foods fortified with thiamin may account for the reduced intake because, in Australia, only fortification of thiamin in wheat flour for bread making is mandatory [Food Standards Australia & New Zealand (FSANZ), 2008]. The intake of vitamin A may

have been overestimated when reporting prediagnosis diet as a result of generalisations about the consumption of vitamin A-rich 'orange-coloured vegetables'. However, this was less likely because it was relevant only to women and was not observed for any other nutrient. An inadequacy of vitamin A intake in association with the GFD has not been reported previously.

Because gluten-containing cereals are a major source of dietary fibre, patients with CD may be at higher risk of consuming an inadequate fibre intake, which is consistent with other studies (Thompson, 1999; Thompson *et al.*, 2005; Wild *et al.*, 2010). Compounding this is the potential that gluten-free foods contain less fibre than gluten-containing equivalent foods; many are prepared from refined maize flour and white rice, which are lower in fibre (0.5 g and 0.8 g per 100 g, respectively) than wheat (3.8 g per 100 g) and brown rice (3.2 g per 100 g). The most commonly consumed bread in the present study was the most readily available white loaf containing 3.3 g per 100 g of fibre. Wholegrain wheat-based breads are readily available and typically contain between 4.8–7.8 g per 100 g. Furthermore, it is likely that the volume of breads consumed will be less with the GFD as a result of their inferior texture. By contrast, no similar explanations can be mounted for deficient intake of calcium or of iron in women because the best dietary sources of both are gluten-free. Whether CD specifically reduces meat-seeking eating habits has not been investigated.

The 'no detectable gluten' GFD (<3 p.p.m.) adopted in Australia lies between the very strict zero gluten tolerance approach (as adapted by some groups in the USA) and the more liberal Codex Alimentarius Standard (Codex Alimentarus, 2008) adopted by many European countries and Canada. It is likely that the risk of nutritional adequacies will parallel the strictness of the dietary approach in line with variety of food available to individuals, although this notion has not been formally tested. For example, the Australian GFD permits fruit and nut bars that use wheat-derived glucose syrup as an ingredient, and these are good sources of fibre, vitamins and minerals. By contrast, the more liberal guidelines of the Codex Alimentarius Standard permits up to 20 p.p.m. of gluten in a food that 'is prepared under good manufacturing conditions aimed at achieving the lowest possible levels of gluten resulting from cross contamination' (Health Canada, 2012). Coeliac Australia does not recommend consumption of foods that indicate on the package that they are at risk of cross-contamination (e.g. cereals, nuts and dried beans), therefore limiting the availability of such nutrient dense foods. Additionally, the Australian GFD does not permit the consumption of any oats (even pure uncontaminated), which may further impact on ability to achieve nutritional adequacy because oats contain good amounts of fibre, folate and minerals.

The prevalence of observed dietary nutritional inadequacy in GFD-compliant patients has three important implications. First, it emphasises a key element of the delivery of dietetic education to patients with CD in that it should not only involve the teachings of how to choose gluten-free foods, but also emphasise the importance of nutritional adequacy over the long-term. The dietitian should encourage intake of nutrient-dense foods including wholegrain foods, enriched where possible, legumes, fruits, vegetables, lean meat, fish, chicken and eggs. The long-term use of micronutrient supplements should not be prioritised over achieving nutritional adequacy from dietary intake alone. Whether special dietary recommendations (nutritional targets) should be set, such as the calcium recommendations set for CD and osteoporosis in the UK (British Society of Gastroenterology, 2007) is not assessable on the basis of the present study because it was not designed to address the relationship between the effect of dietary nutritional adequacy without the impact of supplementation. Second, it highlights the need to promote the nutritional risks of the GFD identified in the present study. The CD-specific nutritional inadequacy of thiamin, particularly, and the high risk of inadequate folate intake should be addressed. Finally, the implications for the food manufacturing industry are clear with regard especially to the development of recommendations for the micronutrient fortification with, for example, thiamin and folate of gluten-free foods in consultation with key stakeholders. Two major studies undertaken in America found that many gluten-free foods contained significantly less thiamin, riboflavin, niacin (Zarkadas & Case, 2005), iron and folate (Thompson, 1999) compared to their fortified gluten-containing comparative products. The Codex Standard indicates that gluten-free foods that are dietary staples (e.g. flour, bread) should supply approximately the same amount of vitamins and minerals as the food they replace (Case, 2005), although there are no regulations governing this in many countries such as Australia.

In conclusion, patients consuming a GFD are at risk of nutritional inadequacies and excesses. Some may be a result of general community eating habits, some to preexisting individual eating habits, and some specifically to the GFD, although such attributions require evaluation in further specifically targeted investigations. Nevertheless, it is reasonable that all aspects, and not just how to avoid gluten, should be addressed by those educating patients on the GFD and further attention be paid to the fortification of gluten-free foods, so that they at least match the micronutrient content of the foods they replace.

Acknowledgments

Dr Frank Parker, Monash University Department of Medicine, Box Hill Hospital, is thanked for assistance with the statistical analyses.

Conflict of interest, source of funding and authorship

SJS has published seven cookbooks directed towards issues of coeliac disease.

SJS was supported by a Dora Lush Scholarship from the NHMRC of Australia and received a Grant in Aid from the Australian and New Zealand Coeliac Research Fund.

SJS devised the study, performed the study, analysed the results and wrote the paper. PRG assisted in the design of the study, contributed to the analysis and interpretation of the results, as well as the writing of the paper. All authors critically reviewed the manuscript and approved the final version submitted for publication.

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