

Intake of dietary iron is low in patients with Crohn's disease: a case–control study

Miranda C. E. Lomer^{1*}, Kamelia Kodjabashia¹, Carol Hutchinson², Simon M. Greenfield³, Richard P. H. Thompson¹ and Jonathan J. Powell²

¹Gastrointestinal Laboratory, The Rayne Institute, St Thomas' Hospital, Lambeth Palace Road, London SE1 7EH, UK

²Department of Nutrition and Dietetics, Franklin-Wilkins Building, King's College London, 150 Stamford Street, London SE1 9NN, UK

³Department of Gastroenterology, Queen Elizabeth II Hospital, Howlands, Welwyn Garden City, Hertfordshire AL7 4HQ, UK

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Patients with Crohn's disease (CD) often experience Fe deficiency (ID) and frequently alter their diet to relieve abdominal symptoms. The present study set out to assess whether patients with CD have dietary habits that lead to low Fe intakes and/or reduced bioavailable Fe compared with control subjects. Patients with asymptomatic CD were matched to controls (n 91/group). Dietary intakes of Fe and contributions from different food groups were compared using a 7 d food diary. Promoters and inhibitors of non-haem Fe absorption were investigated and a recently published algorithm was applied to assess bioavailable Fe. Fewer patients than controls met the reference nutrient intake for Fe (32% CD patients *v.* 42% controls). Overall, patients had significantly lower mean Fe intakes (by 2.3 mg/d) and Fe density (by 0.26 mg/MJ (1.1 mg/1000 kcal)) compared with controls (both $P < 0.001$). Differences were mainly due to a preference among CD patients for low-fibre non-Fe fortified cereals, particularly breakfast cereals. In particular, control subjects had higher Fe intakes than matched CD subjects for men ($P < 0.001$) and women less than 50 years ($P = 0.03$). Intakes of both ascorbic acid ($P < 0.001$) and phytic acid ($P < 0.01$), but not animal tissue ($P = 1.0$), were lower in patients with CD, but these had no overall effect on the predicted percentage of bioavailable Fe. Thus total bioavailable Fe was reduced in patients with CD due to lower intakes ($P < 0.01$). Dietary Fe intakes are low in CD patients, which may contribute to an increased risk of ID and anaemia. Changing dietary advice may compromise perceived symptoms of the disease so the need for Fe supplementation should be carefully considered.

Iron intake: Diet: Iron deficiency: Crohn's disease

Crohn's disease (CD) is an inflammatory bowel disease characterised by patchy, transmural inflammation of mainly the ileum and colon. Although formal prospective studies do not exist it is generally accepted that Fe deficiency (ID) is common in CD (Gasche *et al.* 1994, 1997; Harvey *et al.* 1998; Mamula *et al.* 2002; Erichsen *et al.* 2003). This is based upon (a) frequent clinical observations; (b) retrospective analysis and audit of patient notes (Child *et al.* 1973; Thomson *et al.* 1978; Gasche *et al.* 1994; De Silva *et al.* 2001a,b; Oldenburg *et al.* 2001); (c) response to oral or intravenous Fe therapy (Gasche *et al.* 1997, 2001; Harvey *et al.* 1998). The latter point is important as anaemia of chronic disease can be difficult to separate from ID but, in a series of carefully controlled studies, Gasche *et al.* (1997, 2001) have demonstrated that about 75% of patients with anaemia and CD respond to Fe therapy leading also to a significant improvement in their quality of life. Reasons for ID in CD are not

completely clear but, being an inflammatory bowel disease, loss of blood and protein in the gastrointestinal tract is one obvious risk and increased mucosal Fe levels seem probable in inflammatory bowel disease (Millar *et al.* 2000; Erichsen *et al.* 2003). However, unlike with coeliac disease, Fe malabsorption is unlikely to occur in CD since Fe absorption occurs proximally while the disease predominates distally. Indeed, limited studies have suggested that Fe absorption is unaltered in patients with CD (Bartels *et al.* 1978). However, sub-optimal dietary Fe intake has not been widely considered as a potential contributor to ID in CD, and yet deserves attention because food aversions and self-reported food intolerance are common in this patient group (Ballegaard *et al.* 1997; Mishkin, 1997). Thus patients often alter their diet to reduce abdominal symptoms, such as pain and diarrhoea (Ballegaard *et al.* 1997).

A number of studies have evaluated dietary Fe intake in inflammatory bowel disease (Hodges *et al.* 1984; Gee *et al.*

1985a,b; Imes *et al.* 1987; Geerling *et al.* 1998), but have generally involved small numbers, lacked appropriate control groups and often had insufficient specificity or selectivity to estimate Fe intakes with any confidence.

Dietary Fe occurs in two forms, namely haem and non-haem. In an omnivorous diet, approximately 10% of total dietary Fe is haem Fe, which is obtained from meat, poultry and fish (Monsen *et al.* 1978). The remaining 90% of dietary Fe is non-haem and mainly obtained from plant sources. The absorption of haem and non-haem Fe ranges from 15 to 35% and 2 to 20% respectively, depending on many factors, including the presence of dietary promoters and inhibitors for non-haem Fe absorption (Morris, 1987; Monsen, 1988; Hunt, 1996).

The present study investigated whether dietary Fe intake is lower in patients with CD compared with controls. Since the total amount of Fe in the diet is a poor indicator of bioavailable (absorbable) Fe (Monsen *et al.* 1978; Tseng *et al.* 1997; Hallberg & Hulthen 2000; Reddy *et al.* 2000), a recently described Fe absorption algorithm (Reddy *et al.* 2000) was also used to estimate the amount of dietary Fe that was potentially bioavailable in the two groups.

Materials and methods

Study design

Patients with CD (aged 23–65 years; *n* 91) were recruited from gastrointestinal outpatient clinic records at St Thomas' Hospital (London), Queen Elizabeth II Hospital (Welwyn Garden City, Hertfordshire) and The Lister Hospital (Stevenage, Hertfordshire). Control subjects (aged 23–66 years; *n* 91) were recruited from general practitioner (GP) clinics local to the hospitals; namely, Lambeth Walk Group Practice (London) and Bridge Cottage Surgery (Welwyn Garden City, Hertfordshire). The CD patients and controls were matched for age (± 5 years), sex, ethnicity, area of residence and social class. The present study size would detect a significant difference of 3.0 mg/d in total Fe intake, assuming a standard deviation in each group of 6.0 mg (Hodges *et al.* 1984; Gee *et al.* 1985b; Department of Health, 1991) with 80% power at the 5% significance level. Local ethics committees for Guy's and St Thomas' NHS Trust and the East and North Hertfordshire NHS Trust approved the study, and all subjects were invited to take part over the course of 1 year (September 1999 to August 2000).

Subjects

Prospective cases (aged 19–68 years; *n* 302) and controls (aged 18–70 years; *n* 547) were initially contacted by post either by their consultant gastroenterologist (cases) or their GP (controls). Those willing to participate returned a pre-paid reply card to the investigators for potential recruitment into the study.

Cases

Patients with CD were invited by their consultant gastroenterologist to respond to the investigators if they were in

self-reported disease remission (median 12 months). Upon recruitment to the study, symptoms needed to be absent for at least 1 week. However, the interval since each patient's last relapse was recorded, because disease severity and activity can influence appetite (Geerling *et al.* 1998; Riordan *et al.* 1998). Three patients with CD were taking prescribed oral Fe medication (ferrous sulfate) and, as for controls, neither this nor self-prescribed supplements were included in the results for dietary Fe intakes. This was to ensure that intakes reflected only nutrients coming from the diet and not from supplements.

Controls

Individuals were chosen at random by administrative staff from GP records held on a database and then those without diagnosed gastrointestinal or other chronic disease were contacted by their GP. Controls who replied to the invitation provided a brief medical history to confirm the absence of gastrointestinal or chronic disease and were matched to the responding patients with CD (1:1) for age (± 5 years), sex, ethnicity, social class and area of residence. All recruited subjects were allocated to a social class according to the criteria of the Registrar General's scale (Reid, 1980). Although the groups were not matched for BMI there were no significant differences between cases (23.3 (SD 4.3) kg/m²) and controls (24.1 (SD 3.7) kg/m²) (paired Student's *t* test; *P*=0.2).

Dietary assessment

Following recruitment and informed consent, all subjects were taught to complete a validated 7 d food diary (Bingham *et al.* 1997). Seasonal differences in food choice were restricted by ensuring that the matched cases and controls were selected at the same time of year, although seasonal variations in food supply in industrial societies are small (Bingham, 1987).

Each interview lasted approximately 30 min and the subjects were shown how to complete the food diary, using their previous day's dietary intake as an example. This indicates the detail required and helps to eliminate any bias in the subject's response (Bingham *et al.* 1997). The subjects were requested to record food items at the time of eating to minimise reliance on memory (Buzzard, 1998), thus limiting recall error and reducing the risk of omitting dietary items or misinterpreting portion sizes.

The food diary contained full instructions, examples of descriptions of meals and seventeen sets of photographs with three portion choices for each food. Photographs improve estimates of portion size (Faggiano *et al.* 1992; Nelson *et al.* 1996), and so the subjects were taught how to use the portion-size photographs as a guide for other similar foods. Where appropriate, the subjects were also allowed to state portion sizes in convenient household measurements or pack sizes if they preferred. Instructions were given to clearly describe recipes, cooking methods, and the type and brand name of food and drink consumed.

The participants were asked to fill in the remaining 6 d of the diary maintaining their usual eating habits and to return the completed diary in a pre-paid envelope. In addition, the

subjects were asked to answer a number of general questions regarding their dietary intake, such as the type of milk (whole, semi-skimmed or skimmed) most frequently used during the recording period. The questions served as a crosscheck and were intended to confirm the accuracy of the account (Bingham, 1987).

Subjects who failed to return their diary 7 d after the expected date of completion were contacted by telephone and, if necessary, a second telephone reminder was given 1 week later.

Nutrient database

Energy and nutrient intakes were generated using a nutrient analysis database program (Lomer, 2002) and the food composition tables for the UK (Holland *et al.* 1991). The database was updated with published values for phytic acid (Harland & Oberleas, 1987) and estimated amounts of animal tissue (Monsen & Balintfy, 1982), which are two factors in the Fe absorption algorithm (Reddy *et al.* 2000). For quality control, food records were screened for errors before analysis. Data were crosschecked for input errors, such as duplicate entries and values outside the expected range for weight of portion size (g), energy (kJ) and a few selected nutrients (Lomer, 2002).

Data analysis

Comparisons were made between the patients with CD and the controls using the paired Student's *t* test for continuous data and the χ^2 test for categorical data. In all tests significance was assumed where $P \leq 0.05$ and results are expressed as mean values and standard deviations. Where multiple comparisons are presented of independent data the *P* values are adjusted according to the Bonferroni method for limited multiple comparisons (i.e. *P* value \times number of comparisons) and the treatment of data is given in the footnotes to each Table. Analyses were carried out for energy, protein, fat, carbohydrate, Fe intake and Fe density (i.e. mg/MJ and mg/1000 kcal). Fe intakes were compared with the dietary reference values and according to different Fe requirements (Department of Health, 1991). Hence, the cases and controls were subdivided to investigate Fe intakes in male subjects, and in females under and over 50 years of age, which is a commonly used arbitrary cut-off for menopausal status. As noted earlier, analyses were also carried out to calculate the contribution of different food groups to Fe intake and to assess potentially bioavailable haem and non-haem Fe in the cases and controls. Potentially bioavailable dietary haem Fe was assumed to be 25% in all subjects, based on studies in healthy volunteers consuming mixed meals (Monsen *et al.* 1978; Hunt & Roughead, 2000). Recently two Fe absorption algorithms have been published (Hallberg & Hulthen, 2000; Reddy *et al.* 2000) that take into account the combined effect of enhancers and inhibitors of non-haem Fe absorption in mixed meals. In the present study an adapted algorithm of Reddy *et al.* (2000) was used since this is easily applied and involves only three major dietary factors affecting Fe bioavailability (ascorbic acid, phytic acid and animal tissue). Hence:

$$\text{Ln potentially bioavailable Fe (\%)} = \text{Ln Fe absorption adjusted for serum ferritin concentration of } 30 \mu\text{g/l (\%)} = 1.9786 + (0.0123 \times \text{animal tissue per d/3 (g)}) - (0.0034 \times \text{phytic acid per d/3 (mg)}) + (0.0065 \times \text{ascorbic acid per d/3 (mg)}).$$

In the originally described algorithm (Reddy *et al.* 2000), absorption of dietary Fe is determined by the Fe quantity and quality and by the individual's capacity for Fe absorption. The latter is estimated from plasma ferritin levels, but in chronic disease, such as CD, this may be misleading as ferritin can be elevated independently of Fe status. In any case, the present study aimed to identify dietary Fe intake in CD patients rather than its absorption and so, without reference to serum ferritin levels, potentially bioavailable Fe rather than Fe absorption was estimated as shown in the equation shown earlier. Dietary factors (weight/d) are each divided by 3 as the original algorithm is based upon individual meals rather than daily intakes.

Results

Subjects

Overall, 302 cases were invited and 114 replied. Of these, 102 matched the recruitment criteria but then two never returned diaries and nine others could not be matched to controls. Controls continued to be recruited until matching to the ninety-one cases was achieved. Invitations were sent to 547 controls; 126 replied and 110 were recruited. Six of these did not return diaries and thirteen could not be matched.

Iron intake

Mean energy, protein, fat and carbohydrate intakes were not significantly different between the patients with CD and controls, whereas mean Fe intake was significantly lower in the patients by 2.3 mg/d ($P < 0.001$), as was mean Fe density by 0.26 mg/MJ (1.1 mg/1000 kcal) ($P < 0.001$; Table 1). Thus fewer patients with CD compared with the controls met the reference nutrient intake (RNI) (Department of Health, 1991) for Fe (32% CD patients *v.* 42% controls; Figs. 1 and 2). All subgroups of patients with CD had, on average, lower mean Fe intakes than the controls, but this only reached significance for males ($P < 0.001$) and females 50 years of age or under ($P = 0.03$; Fig. 1). In the CD patients, there was no obvious association between Fe intakes and interval since the last disease relapse (Pearson's correlation $r = 0.1$; $P = 0.2$) and there was no significant difference in Fe intake between the patients with or without disease relapse in the previous 12 months ($P = 0.9$).

Food groups

Cereals, meat and vegetables contributed 80 and 76% of the dietary Fe for the cases and controls, respectively. However, cereals contributed 1.7 mg less dietary Fe in the cases than in controls ($P < 0.001$; Table 2), accounting for the majority of the difference between the groups. On further analysis, the mean Fe intake from bread and

Table 1. Nutrient intakes in Crohn's disease (cases) and controls*
(Mean values, standard deviations and ranges)

	Controls (n 91)			Cases (n 91)			P†
	Mean	SD	Range	Mean	SD	Range	
Energy: MJ/d	8.795	2.13	3.427–14.175	8.707	2.19	4.025–14.422	
kcal/d	2102	509	819–3388	2081	523	962–3447	1.0
Protein (mg/d)	79.2	19.8	25–131	74.4	19.2	37–116	0.5
Fat (g/d)	81.0	24.5	21.6–152.4	86.0	27.8	17.5–169.9	1.0
Carbohydrate (g/d)	238	61.2	57.1–370.0	242	68.2	100–410	1.0
Fe (mg/d)	11.6	4.2	5.1–27.5	9.3	3.2	3.3–20.6	<0.001
Fe density: mg/MJ	1.34	0.45	0.74–3.18	1.08	0.26	0.48–2.06	
mg/1000 kcal	5.6	1.9	3.1–13.3	4.5	1.1	2.0–8.6	<0.001

* For details of subjects and procedures, see pp. 142–143.

† P values are presented as the original P value \times 5 (since five independent comparisons were made) and are shown as 1.0 for all results \geq 1.0.

breakfast cereals was less in the cases than controls, differing by 0.3 mg/d ($P=0.04$) and 1.5 mg/d ($P<0.001$), respectively (Table 2).

Potentially bioavailable haem and non-haem iron

The mean intake of haem Fe and, therefore, its potential bioavailability were similar for the controls and patients with CD and represented less than 10% of total Fe intake and approximately 15% of potentially bioavailable Fe (Table 3).

The mean intake of non-haem Fe was 2.4 mg/d lower in the patients with CD than in the controls ($P<0.001$). Compared with the controls, the patients with CD had significantly lower mean intakes of ascorbic acid ($P<0.001$), predominantly due to the consumption of less fruit, and lower mean intakes of phytic acid ($P<0.01$), whereas consumption of animal tissue (meat, poultry and fish) was similar for both groups ($P=1.0$; Table 3). These three factors were used in the algorithm for assessing non-haem Fe bioavailability (see p. 143) and similar percentages were observed in the two groups (10.6% patients and 10.7% controls, $P=0.9$; Table 3). Thus, the total dietary Fe

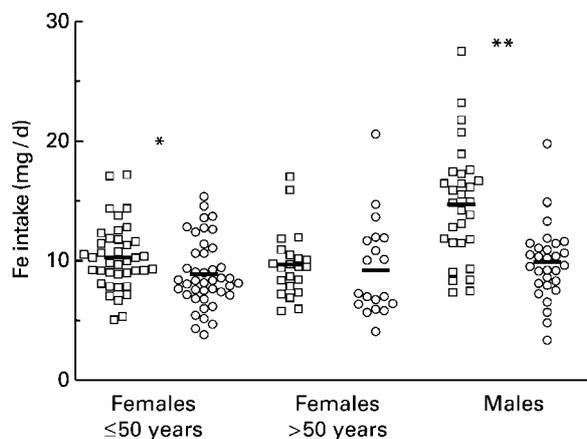


Fig. 1. Mean daily Fe intakes of male and female Crohn's disease cases (○) and controls (□) aged 50 years or under and over 50 years of age. Mean value (—) for the Crohn's disease cases was significantly lower than for the controls: * $P=0.03$, ** $P<0.001$.

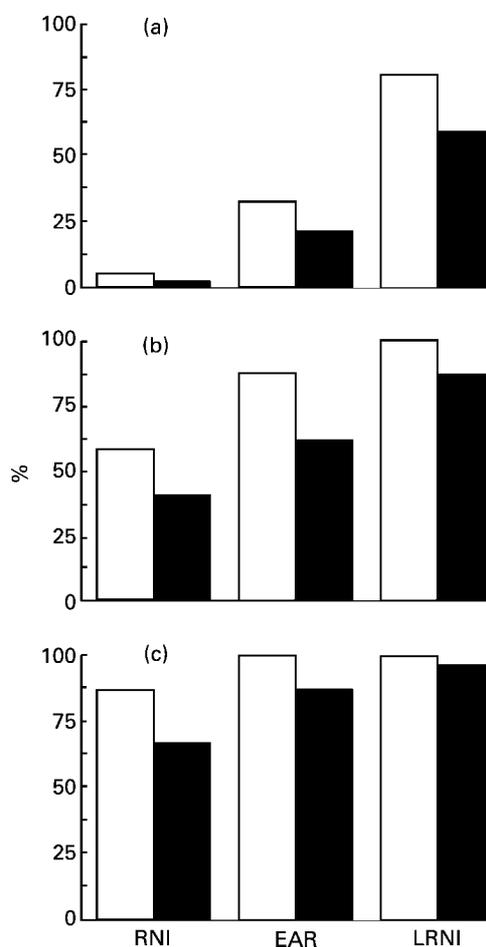


Fig. 2. The percentages of Crohn's disease cases (■) and controls (□) who met the dietary reference values for Fe (Department of Health, 1991) for (a) females aged 50 years or under, (b) females aged over 50 years and (c) males. Reference nutrient intakes (RNI) for Fe are 14.8 mg/d (females aged 50 years or under), and 8.7 mg/d (males, and females aged over 50 years). Estimated average requirements (EAR) for Fe are 11.4 mg/d (females aged 50 years or under), and 6.7 mg/d (males, and females aged over 50 years). Lower reference nutrient intakes (LRNI) for Fe are 8.0 mg/d (females aged 50 years or under), and 4.7 mg/d (males, and females aged over 50 years).

Table 2. Iron intake from the top contributing food groups in patients with Crohn's disease (cases) and controls* (Mean values and standard deviations)

	Fe intake (mg/d)				P†
	Controls		Cases		
	Mean	SD	Mean	SD	
Cereals	5.6	3.6	3.9	2.0	<0.001
Bread‡	2.4	1.0	2.1	1.2	0.04
Breakfast cereals‡	2.4	3.4	0.9	1.2	<0.001
Meat	1.6	1.0	1.9	1.4	0.1
Vegetables	1.6	0.8	1.6	1.0	0.9

* For details of subjects and procedures, see pp. 142–143.

† These outcomes represent subgroup analysis from a previously established difference in Fe intake (see Fig. 1) so *P* values have not been presented with Bonferroni correction.

‡ Selected food subgroups.

(haem and non-haem) that was potentially bioavailable was still 17% lower in the cases than in the controls ($P < 0.01$; Table 3).

Discussion

Anaemia in patients with CD may be a consequence of inflammation (anaemia of chronic disease); however ID also occurs frequently and is estimated to occur in about 30% of patients at any one time (Gasche *et al.* 1994; Oldenburg *et al.* 2001). Reasons for this are not completely clear although abnormal Fe loss in the gastrointestinal tract is probable. However, the present study also suggests that significantly reduced non-haem Fe intake occurs in patients with CD probably as a result of avoidance of certain Fe-rich and fortified foods. Typically these are 'fibrous' in nature and may be avoided by patients for fear of exacerbating symptoms. The present study now

shows that, overall, this results in an intake of about 20% less dietary Fe than in a carefully matched control population.

Previous studies have suggested insignificant differences in Fe intakes between CD patients and controls, but have been underpowered (Geerling *et al.* 1998) and/or lacking control groups (Hodges *et al.* 1984; Imes *et al.* 1987). Moreover these previous studies generally assessed Fe intake as one of many variables and/or used food-frequency questionnaires. The former further reduces power while the latter is only semi-quantitative, often overestimating absolute nutrient intakes and requiring large numbers of subjects for best usage (Bingham, 1987). Indeed, in former studies, energy and Fe intakes were higher than in the present investigation and were surprisingly high compared with expected national averages (Hodges *et al.* 1984; Imes *et al.* 1987; Geerling *et al.* 1998). The present study used a 7 d food diary, which compares well with 16 d weighed records for the correct ranking of subjects and has been validated in the UK population (Bingham *et al.* 1997) although mild to moderate under-reporting can still occur. Overall, energy intakes may have been marginally low in the present study (about 8.8 MJ (2100 kcal)/d) but neither this nor BMI varied between the groups suggesting that observations between the groups remain valid.

The male control subjects consumed 14.7 mg Fe/d, which is in close agreement with British dietary survey data (Gregory *et al.* 1990). However, both groups of female control subjects had low Fe intakes compared with the British survey data with females aged 50 years or under consuming the least compared with their RNI. This group has a high requirement for dietary Fe due to the extra Fe losses during menstruation, but often fail to meet the RNI of 14.8 mg/d in the UK (Department of Health, 1991) or the RDA of 15 mg/d in the USA (National Research Council, 1989). Most notably, however, the matched subjects with CD (females aged 50 years or

Table 3. Potentially bioavailable haem and non-haem iron intakes in Crohn's disease (cases) and controls* (Mean values and standard deviations)

	Controls		Cases		P†
	Mean	SD	Mean	SD	
Haem Fe (mg/d)‡	0.78	0.49	0.90	0.59	0.2
Potentially bioavailable haem Fe (mg/d)§	0.19	0.12	0.22	0.15	0.2
Non-haem Fe (mg/d)	10.8	4.1	8.4	3.0	<0.001
Animal tissue (g/d)‡	97	50	93	43	1.0
Ascorbic acid (mg/d)	118	63	80	54	<0.001
Phytic acid (mg/d)	285	239	176	169	<0.01
Bioavailability of non-haem Fe (%)	10.7	3.6	10.6	2.48	0.9
Potentially bioavailable non-haem Fe (mg/d)	1.14	0.55	0.89	0.37	<0.001
Total potentially bioavailable Fe (mg/d)	1.34	0.61	1.11	0.46	<0.01

* For details of subjects and procedures, see pp. 142–143.

† Fe-related outcomes represent subgroup analysis from a previously established difference in Fe intake (see Fig. 1) so, in these cases, *P* values have not been presented with Bonferroni correction. For animal tissue, ascorbic acid and phytic acid, *P* values are presented as the original *P* value $\times 3$ (since three independent comparisons were made) and are shown as 1.0 for results ≥ 1.0 .

‡ The trend towards a higher intake of animal tissue but a lower intake of haem Fe in controls compared with cases is explained by group preferences for red meat (tending to be higher in cases) or poultry and fish (tending to be higher in controls).

§ Based upon 25% bioavailability (Monsen *et al.* 1978; Harland & Oberleas, 1987; see p. 143)

|| Adapted from the equation of Reddy *et al.* (2000; see p. 143).

under) had even lower Fe intakes and yet probably have greater dietary Fe requirements due to protein and blood losses during active disease (Oldenburg *et al.* 2001). Female patients of 50 years or under make up a large proportion of patients with CD since, presently, it is an increasingly prevalent disease, with a slight female bias (Lashner, 1995) that tends to affect younger individuals (National Association for Colitis and Crohn's Disease, 2002). Overall it is striking that the Fe intakes in the present study not only failed to reach the RNI in many patients, but also were even lower than the Fe intakes in a matched control population. These findings suggest that one of the reasons for the suggested high prevalence of ID in patients with CD is sub-optimal Fe intake.

In the present study, all patients with CD had been in remission for at least 1 week, which, for some, would be a relatively short period of time (19% for 1–4 weeks) although the median was 12 months. Intakes of Fe could have been altered in patients who had recently experienced a period of increased disease activity, since it is recognised that energy intakes are significantly reduced in active CD (Thomas *et al.* 1993; Rigaud *et al.* 1994) but not during periods of disease remission (Thomas *et al.* 1993). However, mean energy and macronutrient intakes were not significantly different in the patients and controls. Moreover, there was no association between Fe intakes and time since the last relapse of disease or between those with recent relapses (< 1 year) *v.* those with longer-term remission (> 1 year). Taken together, these data suggest that reduced dietary Fe intake in patients with CD was due to the habitual consumption of foods containing less Fe, and not due to reduced food or Fe intake in response to disease activity.

Cereals, meat and vegetables provide 80% Fe in the British diet (Gregory *et al.* 1990). In the present study meat provided around 10% dietary Fe intake. Although haem Fe is of relatively high bioavailability, meat is not generally a high source of the total dietary Fe intake in the UK (typically < 15%; Lynch, 2002). This is in spite of the fact that there were only three vegetarians in the control group and one in the CD group and that red meat was not consumed by only five controls and four cases. A similar contribution to dietary Fe came from vegetables, mostly potatoes, peas, green beans, broccoli and baked beans. However, cereal-based foods, due to fortification, were by far the greatest contributor to dietary Fe as noted elsewhere in the UK (Gibson, 1999). The bioavailability of Fe in fortified cereals is influenced by dietary components such as phytic acid and ascorbic acid (Gibson, 1999) but most Fe-fortified breakfast cereals, which are naturally high in phytic acid, are not fortified with ascorbic acid.

Patients with CD often avoid specific foods, even in inactive disease, due to the fear of precipitating abdominal symptoms. Indeed, intolerance of cereals, fibrous fruits and vegetables is commonly reported (Ballegaard *et al.* 1997). Hence, in the present study, potential differences in dietary habits leading to lower Fe intakes in cases were investigated. As noted earlier, the patients with CD consumed significantly less Fe from cereals, especially breakfast cereals. High-fibre breakfast

cereals are fortified with more Fe compared with low-fibre breakfast cereals (Holland *et al.* 1991), and it appears that the cases consumed less Fe from breakfast cereals due to a preference for low-fibre cereals.

An estimate of the bioavailability of non-haem Fe in the two groups, by applying the equation of Reddy *et al.* (2000), did not change the overall picture of reduced dietary Fe exposure in CD patients. There was no overall influence of the effects of a low intake of ascorbic acid (promoter) and a low intake of phytic acid (inhibitor) in the patients with CD. However, decreased intakes of these nutrients is in agreement with the findings of past studies (Martini & Brandes, 1976; Thomas *et al.* 1993; Ballegaard *et al.* 1997; Russel *et al.* 1998), in which patients with CD consumed significantly less fruit and vegetables and wholegrain foods compared with controls. Presumably, therefore, on this occasion, the effects of a low-phytic-acid diet counteracted the effects of a low-ascorbic-acid diet when considering overall Fe bioavailability although the limits of such predictive algorithms should be recognised. Absolute bioavailability must be difficult to predict accurately, and clearly varies with each meal and subject factor (Lynch, 2002), so it should only be concluded that there was no obvious compensatory factor in the diet of cases to increase their Fe bioavailability *v.* that of controls.

In conclusion, reduced dietary Fe intake, largely due to the avoidance of certain cereals, and in particular breakfast cereals, may contribute to ID in CD patients. In patients with CD, the reduced intake of ascorbic acid and phytic acid has no overall effect on the potential availability of dietary non-haem Fe. However, changing dietary advice for CD patients may prove unsuccessful, as patients may resist altering their diet for fear of exacerbating abdominal symptoms. Hence, careful dietary Fe supplementation for patients with CD should be especially considered.

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