Implications of low red meat consumption for iron status of young people in Britain

Sigrid Gibson and
Margaret Ashwell

The authors

Sigrid Gibson is Director of SiG-Nurture Ltd, Guildford, UK.
Margaret Ashwell is Director of Ashwell Associates, Ashwell, UK.

Keywords

Surveys, Diet, Meat, Natural products, Age groups

Abstract

The purpose of this paper is to decide whether consumption of red and processed meat is associated with iron intakes and/or iron status among young people in Britain. Data from *The National Diet and Nutrition Survey: Young People Aged 4-18 Years* was used. A total of 1,169 respondents completed a seven-day weighed dietary record and provided a blood sample for iron status. Supplement-users were excluded. RPM was defined as all red meat, meat products and offal excluding white meat. Found that, among girls, iron intakes were low but RPM was not associated with iron intake; boys were less prone to low iron intakes. Opines that low consumption of red meat has adverse implications for iron status. Dietary advice needs to emphasise the importance of bio-available iron sources (such as meat) as well as other factors that increase iron bioavailability.

Electronic access

The Emerald Research Register for this journal is available at
www.emeraldinsight.com/researchregister

The current issue and full text archive of this journal is available at
www.emeraldinsight.com/0034-6659.htm

Introduction

Low iron status is not only of public health concern in developing countries but milder states of iron deficiency are also common in developed countries. In the *National Diet and Nutrition Survey (NDNS)* of young people aged 4-18 yrs, 27 per cent of the oldest girls (15-18 years) had low iron stores (serum ferritin $< 15\ \mu g\ l^{-1}$) while 9 per cent were anaemic (Hb below $120\ g\ l^{-1}$) (Gregory and Lowe, 2000). Among children of school age, low iron status has been associated with poorer IQ scores, maths scores and educational attainment (Nelson, 1996; Halterman *et al.*, 2001) and at least one study has shown that supplementation can benefit some aspects of memory in those who were iron deficient but not anaemic (Bruner *et al.*, 1996). On the other hand, a major recent review has concluded that the evidence from randomised controlled trials that supplementation is beneficial is "reasonably convincing but not conclusive" (Grantham-McGregor and Ani, 2001).

The risk of poor iron status is increased in puberty and adolescence due to a combination of accelerated growth and the onset of menarche in girls, exacerbated by low intakes of iron in some groups. Meat is a major source of well-absorbed "haem" iron, but the consumption of meat (and red meat in particular) appears to be in long-term decline (Robinson, 2001). This is attributable to various factors, from health scares such as new variant Creutzfeld-Jakob Disease (CJD) and cancer (DoH, 1998) to lifestyle trends such as vegetarianism. In the *NDNS*, 10 per cent of 15-18-year-old girls said they were vegetarian or vegan (Gregory and Lowe, 2000). Vegetarianism is particularly prevalent among adolescent young women but it is estimated that many more, who do not describe themselves as vegetarian, may eat red meat infrequently. In the RealEat Poll conducted by Gallup every year, around 12 per cent of women aged 16-24 claim to be vegetarian, but 22 per cent say they eat no red meat (Gallup, 2001).

In a previous paper based on the 1987 *Dietary and Nutritional Survey of British Adults* (Gregory *et al.*, 1990) we reported that adult women (16-64-years-old) who ate least RPM (i.e. <90 g/d) had three times the risk of a low iron intake (below LRNI) compared with high consumers (>140 g/d) (Gibson and Ashwell, 2003). Men who ate no RPM also had a higher risk of low iron intake.

This study was funded by the Meat and Livestock Commission. The National Diet and Nutrition Survey of young people aged four to 18 years was commissioned and funded jointly by MAFF (now the Food Standards Agency) and the Department of Health. Data were obtained from the UK Data Archive at the University of Essex.

© Emerald Group Publishing Limited · ISSN 0034-6659
DOI 10.1108/00346650410568309

Nutrition & Food Science
Volume 34 · Number 6 · 2004 · 253-259

Moreover, anaemia (Hb $<$ 12 g/dl) was twice as prevalent among women who were "average" RPM consumers as among high consumers (12-14 per cent compared with 6 per cent). Inverse trends were also observed for serum ferritin (SF) across the range of RPM, although these were more significant among women.

Our aim was to explore these associations among young people. Our hypothesis was that low consumers of RPM would have poorer iron status, compared with high consumers, whether or not their iron intakes were lower overall.

Methods

The NDNS of young people aged four to 18 years was conducted in 1997 on a nationally representative sample of 2,127 children and young people living in Britain. Weighed dietary records of all food and drink consumed over seven consecutive days were obtained from 1,701 subjects (80 per cent of those interviewed). Participants were required to give detailed descriptions of foods, including brands, and a database of more than 5,000 foods and recipes was used to calculate nutrient intakes from the dietary data. Blood samples (mostly fasting) were obtained from 75 per cent of those completing the dietary records. Biochemical and haematological analyses included haemoglobin (Hb), serum ferritin (SF) and percentage plasma transferrin saturation (TS) and details of procedures are given in the main report (Gregory and Lowe, 2000). The present analysis was based on the sample of 1,169 young people (565 boys and 604 girls) who were not taking iron supplements.

RPM was defined for this study as all meat, meat products and offal (codes 22-25 and 28-32 in the *NDNS* survey) specifically excluding chicken and turkey products and dishes (white meat). We classified boys and girls in each of four age groups (4-6, 7-10, 11-14 and 15-18 years) by quartile of RPM consumption (g/d) to provide four groups equivalent in their age distribution. Mean values for Q1 to Q4 (g/d) were: 28, 68,101,163 (boys) and 15, 50, 79, 131 (girls). Differences between RPM quartiles were assessed by analysis of variance and the post-hoc Bonferroni test, correcting for multiple comparisons. Non-normally-distributed variables (serum ferritin and transferrin saturation) were assessed using non-parametric ANOVA (Kruskal-Wallis). Multivariate logistic regression was used to evaluate the impact of RPM on low iron stores (SF), independently of menarcheal status.

We used three indices (haemoglobin, serum ferritin, and transferrin saturation) to identify low iron status in boys and girls. Chosen cut-offs corresponded to those used in the *NDNS* report:

(Hb $< 115\,\mathrm{g\,L^{-1}}$ for boys and girls aged under 13 years, Hb $< 120\,\mathrm{g\,L^{-1}}$ for girls aged 13 + , $< 130\,\mathrm{g\,L^{-1}}$ for boys aged 13 + ; SF $< 20\ \mu\mathrm{g\,L^{-1}}$ for boys, $\leq 15\mu\mathrm{g\,L^{-1}}$ for girls; TS $<$ 15 per cent for all ages, both sexes).

We sought answers to three key questions:
(1) How much RPM is eaten by schoolchildren?
(2) Do children who eat more RPM have higher intakes of iron?
(3) Do children who eat more RPM have better iron status?

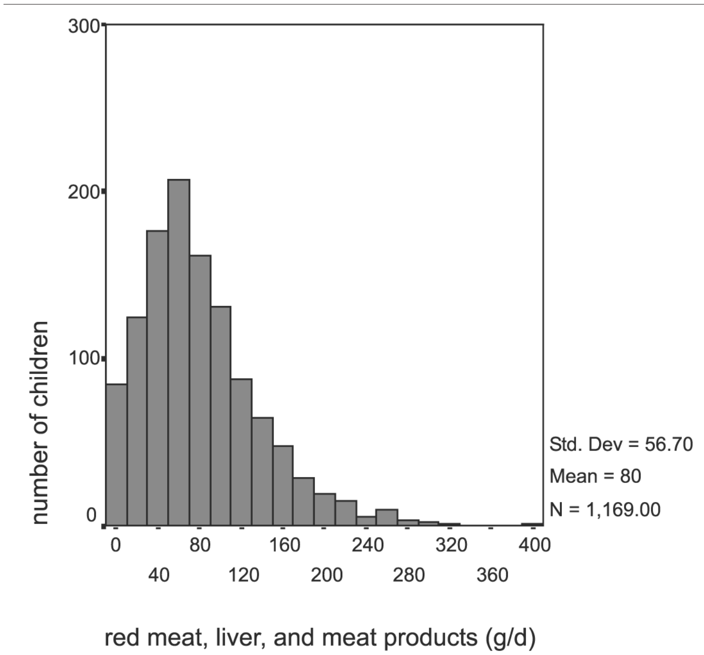
Results

How much RPM is eaten by schoolchildren?
Consumption of RPM in the total sample averaged 80 g per day (Figure 1), with 5 per cent eating no RPM during the study week and 5 per cent eating more than 190 g per day. Statistics for the age-adjusted quartiles are given in Table I.

Do children who eat more RPM have higher intakes of total iron?
Mean iron intakes. Among boys, there was a linear trend of greater iron intake across quartiles of RPM consumption ($P = 0.001$) (Table II; Figure 2). Among girls, there was no association between RPM consumption and iron intake.

Prevalence of low iron intakes. Over 50 per cent of girls had total iron intakes below the Estimated

Figure 1 Histogram of RPM consumption among young people aged four-18 years



Nutrition & Food Science
Volume 34 · Number 6 · 2004 · 253-259

Table I Summary statistics for quartiles of RPM consumption (age adjusted)

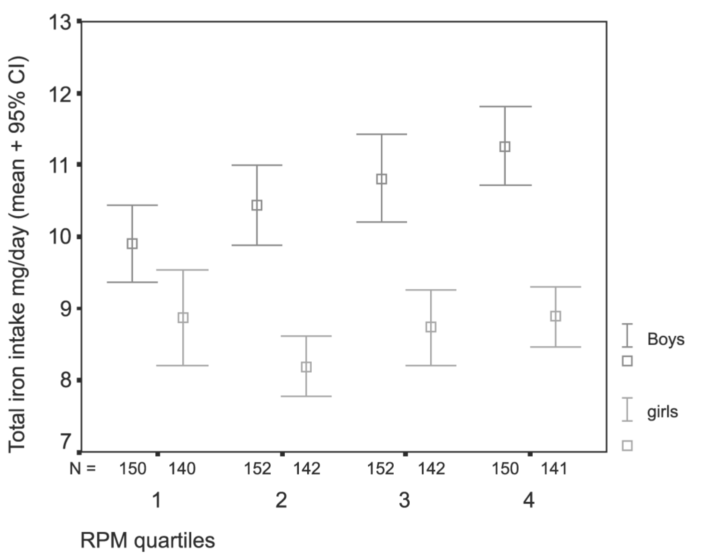
		RPM group (quartiles)				
		1	2	3	4	Total
Boys						
RPM (g d^{-1})	*n* =	150	152	152	150	604
	Mean	28	68	101	163	90
	Median	27	60	99	161	76
	Minimum	0	30	55	79	0
	Maximum	86	127	173	393	393
Girls						
RPM (g d^{-1})	*n* =	140	142	142	141	565
	Mean	15	50	79	131	69
	Median	16	51	78	120	63
	Minimum	0	24	45	69	0
	Maximum	39	70	103	263	263

Table II Iron intake according to RPM consumption

		Quartiles of RPM consumption				
Iron intake (mg d^{-1})		1	2	3	4	Total
Boys	Mean	9.9^a	10.4	10.8	11.3^b	10.6
	SE	0.3	0.3	0.3	0.3	0.1
	Count	150	152	152	150	604
Girls	Mean	8.9	8.2	8.7	8.9	8.7
	SE	0.3	0.2	0.3	0.2	0.1
	Count	140	142	142	141	565
Total	Mean	9.4	9.4	9.8	10.1	9.7
	SE	0.2	0.2	0.2	0.2	0.1
	Count	290	294	294	291	1,169

Notes: ANOVA for linearity: boys, $p = 0.001$; girls = ns; superscripts (a,b etc.) show groups that differ significantly, $p < 0.05$

Figure 2 Iron intake according to RPM level, for boys and girls



Average Requirement (EAR) with 27 per cent having very low iron intakes (below the LRNI). However, as with mean iron intakes, there was no association with RPM consumption (Table III).

Very few boys had iron intakes below the LRNI, but the prevalence of intakes below the EAR decreased across the RPM quartiles (*P* for linear trend <0.0001; Chi-Sq = 16,1df).

Do children who eat more RPM have better iron status?

Median values for serum ferritin were highest among children who ate above-average quantities of RPM (Table IV; Kruskal-Wallis ANOVA: $P = 0.011$ for boys; $P = 0.021$ for girls). Among girls, transferrin saturation was also significantly higher (median 22 per cent (Q3, Q4) vs. 19 per cent (Q1, Q2). However, there was no significant difference in haemoglobin concentration across RPM groups in either sex.

The prevalence of marginal iron status decreased with increasing RPM consumption. Girls in the first and second quartiles (Q1 and Q2) were more likely to have low iron stores (SF) (Figure 3) and low transport iron (TS) (Figure 4), compared with girls in Q3 and Q4. Girls in Q1 were also more likely to be anaemic than girls in other RPM groups (Q1 vs. others: $P = 0.025$; Figure 5). Boys eating least RPM had poorer iron status as judged by low iron stores (SF), but not by the other indices.

Low RPM consumption appears to be a predictor of low iron stores (SF) in both boys and girls. Logistic regressions adjusted for age (and also menarcheal status in the case of girls) confirmed that RPM was independently associated with low SF but poultry consumption was not a significant predictor. The odds ratio of low iron status associated with a below-median consumption of RPM (i.e.Q1 or Q2 vs. Q3 or Q4) was 1.8 for boys ($P = 0.019$) and 2.6 for girls ($P = 0.001$) (Table V). The model for girls gave slightly better prediction than that for boys.

Table III Percentage of children with total iron intakes below EAR and LRNI, according to RPM consumption

		Quartiles of RPM					Chi Sq
		1	2	3	4	Total	*p*
Boys	Number	150	152	152	150	604	
	Below EAR (%)	19	15	11	5	12	<0.0001
	Below LRNI (%)	3	2	1	1	2	Ns
Girls	Number	140	142	142	141	565	
	Below EAR (%)	49	57	54	52	53	Ns
	Below LRNI (%)	25%	31	28	23	27	Ns

Nutrition & Food Science
Volume 34 · Number 6 · 2004 · 253-259

Table IV Iron status according to RPM consumption

		Quartiles of RPM 1	2	3	4	Total	ANOVA *p* value
Boys							
Serum ferritin (μg l^{-1})	*n*	110	115	111	113	449	
	Mean	33.4	36.3	51.1	43.1	40.9	0.011[a]
	SD	17.9	21.0	95.4	31.4	52.1	
	Median	28.5	30.0	37.0	37.0	33.0	
Transferrin saturation (%)	*n*	114	121	122	116	473	
	Mean	22.5	23.1	24.5	24.0	23.5	0.779[a]
	SD	8.3	8.9	10.2	10.6	9.5	
	Median	21.7	23.5	22.7	23.4	22.7	
Haemoglobin (g/dl)	*n*	139	142	145	133	559	
	Mean	13.4	13.5	13.6	13.7	13.6	0.344
	SD	1.2	1.2	1.2	1.2	1.2	
	Median	13.3	13.4	13.4	13.5	13.4	
Girls							
Serum ferritin (μg L^{-1})	*n*	98	99	98	99	394	
	Mean	28.6	31.0	32.8	34.6	31.8	0.028[a]
	SD	19.4	20.1	17.6	23.0	20.2	
	Median	24.0	25.0	30.5	31.0	28.0	
Transferrin saturation (%)	*n*	105	118	115	114	452	
	Mean	19.4	21.3	22.5	22.7	21.5	0.021[a]
	SD	7.8	9.2	8.5	8.6	8.6	
	Median	18.9	19.1	22.0	22.1	20.4	
Haemoglobin (g/dl)	*n*	129	133	130	124	516	
	Mean	12.9	13.0	13.1	13.0	13.0	0.290
	SD	1.0	0.8	1.1	0.9	1.0	
	Median	13.0	13.0	13.4	12.9	13.1	

Note: [a]Non-parametric ANOVA (Kruskal-Wallis)

Figure 3 Prevalence of low iron stores (serum ferritin $<20\ \mu$g L^{-1} (boys) or $<15\ \mu$g L^{-1} (girls))

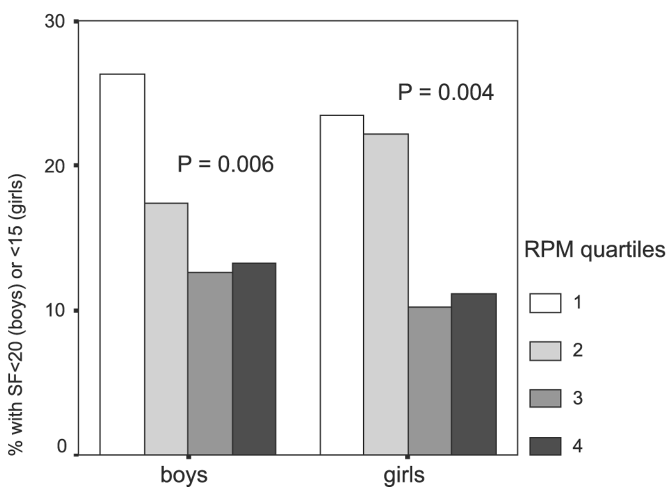
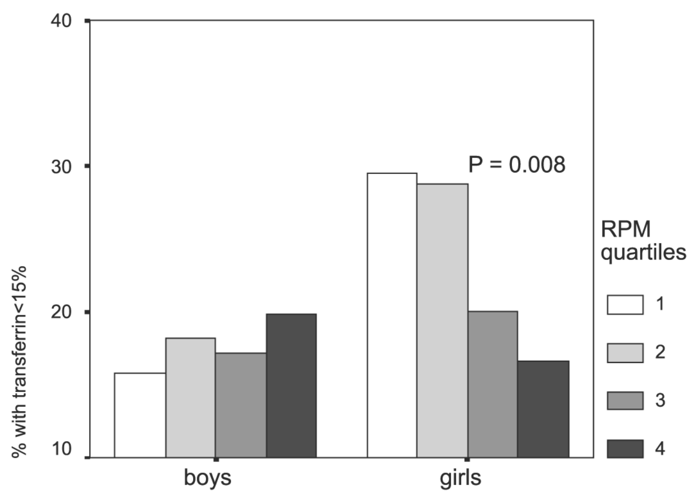


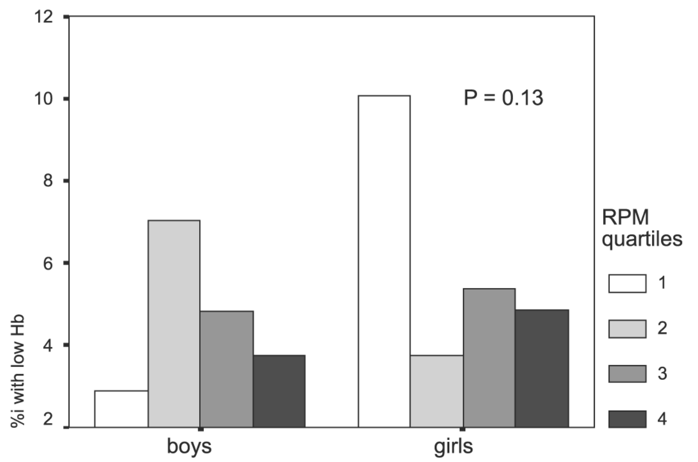
Figure 4 Prevalence of low transferrin saturation (TS <15 per cent)



Discussion

Iron deficiency is arguably the only nutritional deficiency worthy of concern in industrialised countries (Olivares, 1999). While it was once presumed to exert most of its deleterious effects only if anaemia was present, it appears that many organs show morphologic, physiologic, and biochemical changes in iron deficient states before there is any drop in haemoglobin concentration (Beard, 1999). Although the benefits of supplementation remain to be proved conclusively (Grantham-McGregor and Ani, 2001), there may be grounds for a public health nutrition strategy to improve iron status of young women in Britain.

Figure 5 Prevalence of anaemia (Hb $< 120\,g\,L^{-1}$ for girls aged 13+, $<130\,g\,L^{-1}$ for boys aged 13+)



Our observations are in accordance with others who have shown that judgements of the adequacy of iron nutrition (i.e. status) cannot be based on iron intakes alone (Nelson *et al.*, 1993; Samuelson *et al.*, 1996; Rossander-Hulthen and Hallberg, 1996; Spodaryk, 1999; Thane and Bates, 2001). While some vegetarians or non-meat eaters have lower intakes of iron than omnivores, many do not (Worthington-Roberts *et al.*, 1988; Reddy and Sanders, 1990; Ball and Bartlett, 1999) and some may even consume more (Perry *et al.*, 2002; Leblanc *et al.*, 2000) because they make a conscious effort to have a well-balanced diet. Our hypothesis was that iron deficiency (i.e. low iron status) would be most prevalent among low and non-consumers of red meat and meat products, irrespective of their total iron intake. This was indeed found to be the case: girls who ate less RPM made up their iron intake in other ways, but had poorer iron status. Among girls, low iron status was evidenced by lower median values for SF and TS and a higher prevalence of low status using accepted cut-offs (SF $< 15\,\mu g$ l; TS < 15 per cent). Haemoglobin levels are more resistant to depletion, but a weak association was also evident for anaemia (10 per cent of girls in Q1 vs. 5 per cent or less in other quartiles; $P = 0.025$). Boys are generally less prone to iron deficiency because their requirements are lower. Those who ate little or no RPM (Q1) were more likely to have low iron stores (SF $<$ 20ug l) than those eating above-median amounts of RPM, but other less sensitive indices showed no association.

There are two main reasons why eating meat/poultry/fish may benefit iron status over and above their contribution to total iron intake. First, around 40 per cent of the iron in meat, poultry and fish is in haem form and this is better absorbed than non-haem iron (average $\sim$ 25 per cent, range 10 to 40 per cent) (Rossander-Hulthen and Hallberg, 1996). Non-haem absorption is estimated at 5-15 per cent (Monsen, 1988) but this is highly variable due to the effect of dietary enhancers and inhibitors of non-haem absorption (Rossander-Hulthen and Hallberg, 1996; British Nutrition Foundation, 1999). Second, meat, poultry and fish enhance absorption of non-haem iron consumed in the same meal. The mechanism is not clear but may involve cysteine or cysteine-containing peptides (Martinez-Torres *et al.*, 1981; Taylor *et al.*, 1986). The question of whether red meat is superior to poultry and/or fish in enhancing iron status is less well researched. Most observational studies have found a positive association between iron status (Doyle *et al.*, 1999; Donovan and Gibson, 1995; Ortega *et al.*, 1998; Requejo *et al.*, 1999; Thane *et al.*, 2000; Thane and Bates, 2001; Hua *et al.*, 2001; Milman *et al.*, 2003; Thane *et al.*, 2003) and meat consumption and a few have found a stronger and/or a specific association with red meat (Worthington-Roberts *et al.*, 1988; Gibson and Ashwell, 2003; Wolmarans *et al.*, 2003). Our findings of a non-significant association with poultry are tentative and require further exploration, but may

Table V Logistic regression model of low iron stores (serum ferritin $<20\,\mu g\,l^{-1}$ (boys) or $<15\,\mu g\,l^{-1}$ (girls))

	B	SE	*p* value	Odds ratio	95 per cent CI for OR Lower	Upper
Boys						
Age (yrs)	−0.08	0.03	0.012	0.92	0.86	0.98
RPM below median	0.60	0.26	0.019	1.83	1.10	3.04
Constant	−1.0	0.4	0.012	0.37		
Girls						
Age (yrs)	0.01	0.06	0.82	1.01	0.90	1.14
Menarche	1.11	0.49	0.024	3.03	1.16	7.93
RPM below median	0.94	0.29	0.001	2.56	1.44	4.55
Constant	−2.94	0.63	0.0001	0.053		

Notes: Boys: Sensitivity 59 per cent, specificity 62 per cent at cut-point of 17.4 per cent (actual prevalence); Girls: Sensitivity 59 per cent, specificity 74 per cent at cut-point 16.8 per cent (actual prevalence) be biologically plausible given the lower iron and haem iron content of poultry compared with beef, lamb or pork. Fish provided less than 2 per cent of iron in this survey and no association with iron status was apparent.

For older girls, a major factor influencing iron status is the extent of iron losses in menstruation (DoH, 1991). The extent of such losses was impossible to assess in this study, but study design (age-adjustment of the RPM quartiles) meant that a similar proportion (40 per cent) of the girls in each quartile had reached menarche. Furthermore, the independent association between RPM consumption and iron stores was confirmed by adjusting for age and menarcheal status in logistic regression. In this analysis, below-median consumption of RPM was associated with twice the risk of low SF for girls.

From a public health viewpoint, it is appropriate to encourage young women to consume some red meat as part of a balanced diet and to suggest ways of enhancing iron bioavailability for those who choose to be vegetarian. More research is needed on the benefits of different types of meat (and fish) in improving iron status. Finally, more needs to be known about whether low iron stores, as found among some vegetarians and low meat consumers, imply specific adverse health effects (Hunt, 2002).

References

Ball, M.J. and Bartlett, M.A. (1999), "Dietary intake and iron status of Australian vegetarian women", *Am. J. Clin. Nutr.*, Vol. 70 No. 3, pp. 353-8.

Beard, J.L. (1999), "Iron deficiency and neural development: an update", *Arch. Latinoam. Nutr.*, Vol. 49 No. 3, pp. 34S-9S.

British Nutrition Foundation (1999), *Meat in the Diet*, briefing paper, British Nutrition Foundation, London.

Bruner, A.B., Joffe, A., Duggan, A.K., Casella, J.F. and Brandt, J. (1996), "Randomised study of cognitive effects of iron supplementation in non-anaemic, iron-deficient adolescent girls", *Lancet*, Vol. 348 No. 9033, pp. 992-6.

DoH (1991), *Dietary Reference Values for Food Energy and Nutrients for the United Kingdom*, HMSO, London.

DoH (1998), "Nutritional aspects of the development of cancer", *Report of the Working Group on Diet and Cancer*, Committee on the Medical Aspects of Food and Nutrition Policy, Report on Health and Social Subjects, The Stationery Office, London.

Donovan, U.M. and Gibson, R.S. (1995), "Iron and zinc status of young women aged 14 to 19 years consuming vegetarian and omnivorous diets", *J. Am. Coll. Nutr.*, Vol. 14 No. 5, pp. 463-72.

Doyle, W., Crawley, H., Robert, H. and Bates, C.J. (1999), "Iron deficiency in older people: interactions between food and nutrient intakes with biochemical measures of iron; further analysis of the *National Diet and Nutrition Survey* of people aged 65 years and over", *Eur. J. Clin. Nutr.*, Vol. 53 No. 7, pp. 552-9.

Gallup (2001), *RealEat Survey*, Gallup, Princeton, NJ.

Gibson, S. and Ashwell, M. (2003), "The association between red and processed meat consumption and iron intakes and status among British adults", *Public Health Nutr.*, Vol. 6 No. 4, pp. 341-50.

Grantham-McGregor, S. and Ani, C. (2001), "A review of studies on the effect of iron deficiency on cognitive development in children", *J. Nutr.*, Vol. 131 No. 2S-2, pp. 666S-8S.

Gregory, J. and Lowe, S. (2000), "*National Diet and Nutrition Survey*: young people aged four to 18 years", Vol. 1, *Report of the Diet and Nutrition Survey*, HMSO, London.

Gregory, J., Foster, K., Tyler, H. and Wiseman, M. (1990), *Dietary and Nutritional Survey of British Adults*, HMSO, London.

Halterman, J.S., Kaczorowski, J.M., Aligne, C.A., Auinger, P. and Szilagyi, P.G. (2001), "Iron deficiency and cognitive achievement among school-aged children and adolescents in the United States", *Pediatrics*, Vol. 107 No. 6, pp. 1381-6.

Hua, N.W., Stoohs, R.A. and Facchini, F.S. (2001), "Low iron status and enhanced insulin sensitivity in lacto-ovo vegetarians", *Br. J. Nutr.*, Vol. 86 No. 4, pp. 515-19.

Hunt, J.R. (2002), "Moving toward a plant-based diet: are iron and zinc at risk?", *Nutr. Rev.*, Vol. 60 No. 5, pp. 127-34.

Leblanc, J.C., Yoon, H., Kombadjian, A. and Verger, P. (2000), "Nutritional intakes of vegetarian populations in France", *Eur. J. Clin. Nutr.*, Vol. 54 No. 5, pp. 443-9.

Martinez-Torres, C., Romano, E. and Layrisse, M. (1981), "Effect of cysteine on iron absorption in man", *Am. J. Clin. Nutr.*, Vol. 34 No. 3, pp. 322-7.

Milman, N., Byg, K.E., Ovesen, L., Kirchhoff, M. and Jurgensen, K.S. (2003), "Iron status in Danish women, 1984-1994: a cohort comparison of changes in iron stores and the prevalence of iron deficiency and iron overload", *Eur. J. Haematol.*, Vol. 71 No. 1, pp. 51-61.

Monsen, E.R. (1988), "Iron nutrition and absorption: dietary factors which impact iron bioavailability", *J. Am. Diet. Assoc.*, Vol. 88 No. 7, pp. 786-90.

Nelson, M. (1996), "Anaemia in adolescent girls: effects on cognitive function and activity", *Proc. Nutr. Soc.*, Vol. 55 No. 1B, pp. 359-67.

Nelson, M., White, J. and Rhodes, C. (1993), "Haemoglobin, ferritin, and iron intakes in British children aged 12-14 years: a preliminary investigation", *Br. J. Nutr.*, Vol. 70 No. 1, pp. 147-55.

Olivares, M., Walter, T., Hertrampf, E. and Pizarro, F. (1999), "Anaemia and iron deficiency disease in children", *Br. Med. Bull.*, Vol. 55 No. 3, pp. 534-43.

Ortega, R.M., Lopez-Sobaler, A.M., Requejo, A.M., Quintas, M.E., Gaspar, M.J., Andres, P. and Navia, B. (1998), "The influence of meat consumption on dietary data, iron status and serum lipid parameters in young women", *Int. J. Vitam. Nutr. Res.*, Vol. 68 No. 4, pp. 255-62.

Perry, C.L., McGuire, M.T., Neumark-Sztainer, D. and Story, M. (2002), "Adolescent vegetarians: how well do their dietary patterns meet the healthy people objectives?", *Arch. Pediatr. Adolesc. Med.*, Vol. 156 No. 5, pp. 431-7.

Reddy, S. and Sanders, T.A. (1990), "Haematological studies on pre-menopausal Indian and Caucasian vegetarians compared with Caucasian omnivores", *Br. J. Nutr.*, Vol. 64 No. 2, pp. 331-8.

Requejo, A.M., Navia, B., Ortega, R.M., Lopez-Sobaler, A.M., Quintas, E., Gaspar, M.J. and Osorio, O. (1999), "The age at which meat is first included in the diet affects the incidence of iron deficiency and ferropenic anaemia in a group of pre-school children from Madrid", *Int. J. Vitam. Nutr. Res.*, Vol. 69 No. 2, pp. 127-31.

Robinson, F. (2001), "The nutritional contribution of meat to the British diet: recent trends and analyses", *British Nutrition Foundation Bulletin*, Vol. 26 No. 4, pp. 283-93.

Rossander-Hulthen, L. and Hallberg, L. (1996), "Dietary factors influencing iron absorption – an overview", in Asp, N. and Hallberg, L. (Eds), *Iron Nutrition in Health and Disease*, John Libbey, London, pp. 105-15.

Samuelson, G., Bratteby, L.E., Berggren, K., Elverby, J.E. and Kempe, B. (1996), "Dietary iron intake and iron status in adolescents", *Acta Paediatr.*, Vol. 85 No. 9, pp. 1033-8.

Spodaryk, K. (1999), "Disparity between dietary iron intake and iron status of children aged 10-12 years", *Arch. Physiol. Biochem.*, Vol. 107 No. 5, pp. 361-6.

Taylor, P.G., Martinez-Torres, C., Romano, E.L. and Layrisse, M. (1986), "The effect of cysteine-containing peptides released during meat digestion on iron absorption in humans", *Am. J. Clin. Nutr.*, Vol. 43 No. 1, pp. 68-71.

Thane, C.W. and Bates, C.J. (2001), "Iron intakes and status in adolescent British girls according to meat consumption", paper presented at the 17th International Congress of Nutrition, ICN, Vienna.

Thane, C.W., Bates, C.J. and Prentice, A. (2003), "Risk factors for low iron intake and poor iron status in a national sample of British young people aged 4-18 years", *Public Health Nutr*, Vol. 6 No. 5, pp. 485-96.

Thane, C.W., Walmsley, C.M., Bates, C.J., Prentice, A. and Cole, T.J. (2000), "Risk factors for poor iron status in British toddlers: further analysis of data from the *National Diet and Nutrition Survey* of children aged 1.5-4.5 years", *Public Health Nutr.*, Vol. 3 No. 4, pp. 433-40.

Wolmarans, P., Dhansay, M.A., Mansvelt, E.P., Laubscher, J.A. and Benade, A.J. (2003), "Iron status of South African women working in a fruit-packing factory", *Public Health Nutr.*, Vol. 6 No. 5, pp. 439-45.

Worthington-Roberts, B.S., Breskin, M.W. and Monsen, E.R. (1988), "Iron status of pre-menopausal women in a university community and its relationship to habitual dietary sources of protein", *Am. J. Clin. Nutr.*, Vol. 47 No. 2, pp. 275-9.