Iron Intake and Status of Children Aged 6–36 Months in Europe: A Systematic Review

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Abstract

Background: Iron deficiency is the most common nutritional disorder in the world. Young children are particularly vulnerable to the consequences of iron deficiency because of their rapidly developing brain. This review evaluates the prevalence of inadequate iron intake and iron deficiency (anaemia) in European children aged 6–36 months. Summary: Computed searches for relevant articles were performed in November 2013. A total of 7,297 citations were screened and 44 studies conducted in 19 European countries were included in this review. In both infants (6–12 months) and young children (12–36 months), the mean value of iron intakes in most countries was close to the RDA. Nevertheless, proportions of inadequate intakes were considerable, ranging from about 10% in the Netherlands up to 50% in Austria, Finland and the United Kingdom. The prevalence of iron deficiency varied between studies and was influenced by children’s characteristics. Two to 25% of infants aged 6–12 months were found to be iron deficient, with a higher prevalence in those who were socially vulnerable and those who were drinking cow’s milk as a main type of drink in their first year of life. In children aged 12–36 months, prevalence rates of iron deficiency varied between 3 and 48%. Prevalence of iron deficiency anaemia in both age groups was high in Eastern Europe, as high as 50%, whereas the prevalence in Western Europe was generally below 5%. Key Messages: In most European countries, mean iron intakes of infants and children aged 6 to 36 months were found to be close to the RDA. Nevertheless, high proportions of inadequate intakes and high prevalence rates of iron deficiency were observed. Health programs should (keep) focus(ing) on iron malnutrition by educating parents on food choices for their children with iron-rich and iron-fortified foods, and encourage iron supplementation programmes where iron intakes are the lowest.

Introduction

Iron is a mineral that is required for many metabolic processes to take place in the human body. Most importantly, it is part of haemoglobin and therefore essential for the delivery of oxygen to the cells in our body. Iron is also a structural component of many enzymes needed for a wide range of metabolic processes, such as phagocyte antimicrobial activity, neurotransmitter synthesis and function, and the production of DNA, collagen and bile acids [1]. The majority of iron required by the body is acquired from the reutilization of iron released from erythrocyte catabolism.
Iron Intake and Status of European Children

Literature Search Strategy

Computerized searches for relevant articles were performed in Pubmed, Medline, CAB Health and Embase electronic databases in November 2013 using Medical Subject Heading (MeSH) terms or text words iron*, ferrrous, ferric, ferritin, anaemia*, anaemia*, haemoglobin or haemoglobin combined to intake*, diet*, supplement*, status, deplet*, deficien*, concentration* or level* and infant*, toddler*, baby, babies, child* or preschool* (truncated words are followed by an asterisk). Literature searches were limited to articles published after January 2000 in order to retrieve the most up-to-date figures. No language restrictions were applied. Only studies in healthy, term-born children were included, thus excluding children particularly vulnerable to iron deficiency, such as premature infants, low birth weight infants and children with intestinal failure. Subjects from all socioeconomic classes and ethnicity, as well as with different dietary habits were included. Baseline iron intake or status data of children enrolled in randomised controlled trials were not considered, because of potential selection bias due to exclusion criteria (e.g., baseline haemoglobin levels or breastfeeding habits) that were applied. In addition to the computerised literature search, the reference lists of the retrieved papers were searched for other relevant articles. Moreover, we used data gathered by a data collection tool developed by Nutricia Research. This tool is used to describe the nutritional situation of target population groups within a country and consists of two complementary approaches: (1) an extensive literature review covering both scientific published literature, as well as gray literature obtained from Governmental agencies and National and International organizations involved in food, nutrition and public health issues, and (2) interviews with key opinion leaders (mainly paediatricians) and scientific experts in the field of diet and nutrition [14]. In the past two years, nutrient intake and status of infants and young children has been assessed by this tool in six European countries (Austria, France, Germany, Italy, Portugal, and Switzerland).

In the following sections we will first provide an overview of young children’s iron requirement and recommended iron intake. Subsequently, mean intake data are compared to the Estimated Average Requirement (EAR) to estimate the prevalence of inadequate iron intake following the approach of the EURopean micronutrient RECom mendations Aligned (EURRECA) Network of Excellence [15]. In short, the EAR cut-point is calculated as follows: \( z = \frac{\mu - \bar{x}}{SD} \), where \( z \) is the EAR, \( \mu \) the mean iron intake and \( SD \) the standard deviation, assuming a normal distribution. The estimated proportion of cases with inadequate iron intake is found by calculating the area under the normal distribution curve with mean = 0 and SD = 1 to the left of the z value. Similarly to a recent
study of ILSI Europe [16], the EARs for comparison were obtained from the dietary reference values for Food Energy and Nutrients for the United Kingdom [17]. Although these values were set in 1991, there is little evidence to suggest that they have changed from that time to the present [16]. Finally, studies assessing the prevalence of ID and IDA are summarized and discussed.

**Iron Requirement and Recommended Iron Intake**

Physiological requirements for absorbed iron are based on estimates of the sum of basal iron losses, body iron accretion for growth and iron needed to maintain minimal iron stores to ensure normal function. Basal losses of iron are attributed to losses of iron in the faeces, urine, sweat and via exfoliation of epithelial cells, largely from the gastrointestinal tract [18, 19]. This physiological requirement is multiplied by an average figure for the absorption and bioavailability of iron from a typical diet to estimate the EAR, defined as the daily intake level of dietary iron sufficient to meet the needs of 50% of healthy individuals in a particular age and gender group. The RDA is the amount that will meet the daily requirement of almost all (97.5%) individuals and can be calculated by adding two standard deviations to the EAR value. Various institutions and organizations have given widely varying estimates for physiological iron requirements and the bioavailability of dietary iron [20], and hence large variations exist among iron recommendations in different countries [21]. In Europe alone, RDAs of iron for children aged 1–3 years vary between 4 and 15 mg/day [22]. Most European countries, including France, Germany, Italy, Spain, the Netherlands and the United Kingdom, recommend a daily iron intake of 7 or 8 mg/day for children 6–36 months old [22]. The UK EARs that were used to assess the prevalence of inadequate intake in the current review were 6 mg/day for 6–12 months old infants and 5.3 mg/day for 12–36 months olds [23] (UK RDA for 6–12 months and 12–36 months olds is 7.8 and 6.9 mg/day, respectively).

**Literature Search Results**

The initial literature search yielded 7,297 articles (fig. 1). A first screening based on the title and abstract identified 91 eligible articles that were retained for full-text review. This included both articles that were found
by the computerized search of the electronic databases and by the Nutricia Research data collection tool. The data collection tool was especially useful to find publications in local language, data from National dietary surveys and grey literature. Thirteen manuscripts of these 91 studies published subgroup or further analyses as separate manuscripts and were excluded from further review to eliminate duplicate results. Moreover, three manuscripts were excluded because of in- and/or exclusion criteria that were applied. Additionally, studies were excluded if they did not report on: original data (e.g., reviews, opinion articles, letters to the editor; n = 8), prevalence of ID or IDA (e.g., studies that reported only average haemoglobin levels or only the prevalence of anaemia; n = 8), healthy children between 6 and 36 months (n = 6), and if they were conducted in a non-European country (n = 1). Finally, we excluded papers for which we were unable to obtain the full text (n = 8), ultimately resulting in 44 studies included in this review (fig. 1).

Iron Intake

Most of the studies assessing iron intake were carried out in a population-based sample representative of infants and young children in the entire country (table 1). Table 1 summarizes the average intakes and presents the prevalence of inadequate intake of iron. In infants aged 6–12 months old, average iron intakes were close to the RDA of 7.8 mg/day in most European countries for which data were available (fig. 2a). Intakes were found to be lower in Iceland (5.8–6.8 mg/day) [24], in Germany (6.1 mg/day) [25] and in one study performed in the United Kingdom (5.2 mg/day) [26]. The prevalence of inadequate intake ranges between 15 and 30% in 6 to 12 month old infants from France [27], Poland [28] and Sweden [29], while the prevalence of inadequate intake was 6% in 9 month old infants from the Netherlands [30] and 13% in 7–12 month old infants from Spain [31]. Infants from Germany and Iceland had a prevalence of inadequacy around 50%, while prevalence of inadequacy in infants in the United Kingdom varied between 25 and 60% depending on the study [26, 32].

For children aged 12–36 months, average iron intakes in many countries were slightly below the RDA of 6.9 mg/day (table 1; fig. 2b) [25, 27, 30, 32–47]. France, Ireland, the Netherlands, Poland and Spain showed a prevalence of inadequacy below or around 30%, whereas higher inadequacy levels (up to 60%) were found in Austria, Belgium, Germany, Finland and the United Kingdom.

Iron Status

In contrast to the studies assessing iron intake, the majority of studies assessing iron status were conducted in one centre, one city or a specific part of the country, not necessarily representative for the entire country (table 1). In most studies, ID was defined as a serum ferritin (SF) level below 12 μg/l as proposed by the World Health Organization (WHO) [8]. Yet, cut-off values of 10 and 16 μg/l have also been used (table 2). IDA is generally defined as ID in combination with a haemoglobin (Hb) level below 110 g/l. When different cut-off values were described in a paper, the cut-off value for Hb and SF as established by the WHO were used wherever possible.

Prevalence of Iron Deficiency

Twenty-two studies reported on ID prevalence estimates [24, 32, 48–67], of which 15 studies showed results for infants (6–12 months of age) [24, 32, 48–52, 55, 57, 59–61, 63, 64, 67]. In infants, prevalence rates of ID strongly depend on a family’s socioeconomic status. Twenty-six percent of 10–month old French infants coming from socially vulnerable families were found to be iron deficient, compared to 10% of infants not at risk for socioeconomic deprivation [50]. Besides the socioeconomic status, the infant’s current or past type of milk consumption was also an important determinant of ID. Polat et al. showed that 3–4% of 6-month-old infants who were currently fed human milk or formula feeding were iron deficient, compared to 25% of infants who were receiving cow’s milk [51]. In 8 to 12 month old infants, ID was found in 5–12% of currently human milk fed infants, 7–15% of currently cow’s milk fed infants, and 2–4% of infants consuming formula milk [59, 61]. Moreover, in a study in which infants were stratified according to their predominant milk intake (human milk or infant formula) during the first 4 months of life, ID was found in approximately 5% of 4-month old infants, irrespective of the type of milk feeding. At 7 and 10 months of age, around 20% of infants who had been fully breastfed for 4 months were iron deficient compared to none of those receiving infant formula [55]. These results were at least partly explained by the low iron intake throughout the complementary feeding period in formerly fully breastfed infants. In Iceland, the prevalence of ID decreased from 41 to 6% after the publication of revised dietary guidelines, in which (partial) breast feeding was encouraged until 1-year old and iron-fortified formula was rec-
Table 1. Mean iron intake in children aged 6–36 months and the prevalence of children having an intake below the Estimated Average Requirement (EAR) in Europe

| Country [ref.] | Representativea | Intake method | Yearb | Age, months | n (M/F) | Mean iron intake | % below EAR |
|----------------|-----------------|---------------|-------|-------------|---------|-----------------|------------|
| Austria [33]   | Yes             | 3 × 24 h      | 2006  | 12–36       | 183 (83/100) | 5.3  | 2.9      | 50.0       |
| Belgiumd, f [34] | No             | 7 days duplicate | 1999–2000 | 24–47 | 115 | 4.8  | 2.0      | 59.9       |
| Belgiumd [35]  | No              | 3 days DR     | 2002–2003 | 30–48 | 197 (102/95) | boys 7.7 | 2.2 | 13.8 |
|                |                 |               |        |             |          | girls 7.1 | 2.1 | 19.6 |
| Franced, e [27]| Yes             | 3 days WDR    | 2005  | 6           | 58 (36/22) | 8.6  | 2.7      | –          |
|                |                 |               |       | 7           | 66 (35/31) | 8.9  | 2.9      | 15.9       |
|                |                 |               |       | 8–9         | 67 (36/31) | 8.7  | 2.7      | 15.9       |
|                |                 |               |       | 10–12       | 63 (41/22) | 7.4  | 3.0      | 32.0       |
|                |                 |               |       | 13–18       | 66 (36/30) | 7.4  | 2.5      | 20.0       |
|                |                 |               |       | 19–24       | 66 (35/31) | 6.6  | 3.2      | 34.8       |
|                |                 |               |       | 25–30       | 65 (31/34) | 6.5  | 2.7      | 32.8       |
|                |                 |               |       | 31–36       | 62 (31/31) | 6.6  | 2.2      | 27.7       |
| Finlande [36, 37] | Yes          | 3 days DR     | 2003–2004 | 12–23 | 455 (257/198) | boys 6.7 | 2.3 | 27.1 |
|                |                 |               |       |             |          | girls 6.2 | 2.9 | 37.8 |
|                |                 |               |       |             |          | boys 5.2 | 2.1 | 51.9 |
|                |                 |               |       |             |          | girls 4.7 | 1.7 | 63.8 |
|                |                 |               |       |             |          | boys 6.0 | 2.5 | 39.0 |
|                |                 |               |       |             |          | girls 5.7 | 1.9 | 41.7 |
| Germanyd [38]  | Yes             | 3 days WDR    | 1985–1989 | 12–47 | 105 | 5.6  | 2.11 | 10.9       |
| Germanyd [39]  | Yes             | 3 days WDR    | 1986–2000 | 24–47 | 916 | 5.8  | 1.6 | 4.0       |
| Germanyd, e [25]| Yes           | 2 × 3 days WDR | 2001–2002 | 6–11 | 157 (83/74) | boys 6.1 | 3.0 | 48.7       |
|                |                 |               |       |             |          | girls 6.1 | 4.4 | 49.1       |
|                |                 |               |       |             |          | boys 5.9 | 2.8 | 41.5       |
|                |                 |               |       |             |          | girls 5.8 | 3.1 | 43.6       |
|                |                 |               |       |             |          | boys 6.7 | 3.2 | 33.1       |
|                |                 |               |       |             |          | girls 6.0 | 2.6 | 39.4       |
| Netherlandsf [40] | Yes          | 2 days DR     | 2005–2006 | 24–35 | 640 (327/313) | boys 6.6 | 1.6 | 20.2       |
|                |                 |               |       |             |          | girls 6.4 | 1.8 | 26.8       |
| Netherlandsf [30] | Yes          | 2 days DR     | 2002  | 9           | 333 (164/169) | 9.5  | 2.3 | 6.4 |
|                |                 |               |       | 12          | 306 (158/148) | 8.5  | 3.4 | 23.1 |
|                |                 |               |       | 18          | 302 (156/146) | 6.3  | 2.5 | 34.5 |
| Icelandf [24]  | Yes             | 3 days WDR    | 2005–2006 | 91 | 122 | 6.3  | 3.2 | 46.3       |
|                |                 |               |       |             |          | boys 6.3 | 2.7 | 45.6       |
|                |                 |               |       |             |          | girls 6.8 | 4.0 | 42.1       |
|                |                 |               |       |             |          | boys 5.8 | 2.0 | 54.0       |
| Irelandf [41]  | Yes             | 3 days DR     | 2012  | 12–23       | 126 | 7.0  | 3.0 | 28.6       |
|                |                 |               |       | 24–35       | 124 | 7.6  | 3.2 | 23.6       |
| Polandf [42]   | ?               | 24 h          | 2000  | 12–47       | 118 (70/48) | boys 5.4 | 4.9 |
| Polandf, e [28]| Yes            | 24 h          | 2006c | 6           | 43 | 9.7  | 2.8 | –       |
|                |                 |               |       | 12          | 56 | 7.7  | 2.9 | 27.9       |
| Polandf [43]   | Yes             | 3 days DR     | 2010  | 13–36       | 400 (222/178) | 8.5  | 3.0 | 14.3       |
ommended instead of regular cow’s milk as the main substitute for human milk in the second half of the first year [24, 57]. Studies not differentiating between socio-economic status or type of milk consumption reported prevalence rates of ID between 4 and 18% in 6–12 month old infants in various countries [32, 48, 49, 52, 60, 63, 64].

Also in the older age category (>12 months), prevalence rates were dependent on the type of milk consumption. Vincelet et al. categorized 16 to 18 month old children into groups based on their current milk consumption and found that ID was present in 27, 44–59 and 85% of children who predominantly consumed formula milk, cow’s milk and human milk, respectively[54,54]. In the Netherlands, the use of formula and the visit of preschool/day care were associated with a lower prevalence of ID [67]. Among children aged 1 to 3 years, 13% of children who received formula were iron deficient, whereas among children not receiving formula, 30.5% were iron deficient. The intake of >400 ml of cow’s milk per day occurred significantly and more frequently in children with ID than in those without ID [67]. Other studies including children conducted in Albania [53], Greece [56], Iceland [58] and the United Kingdom [62] found similar prevalence rates of ID from 27 to 48%. However, three other studies performed in 13 to 24 month old children from the United Kingdom reported ID prevalence rates of only 3 to 8%, using similar or even stricter definitions of ID [32, 65, 66].

### Table 1. (continued)

| Country [ref.] | Representativea | Intake method | Yearb | Age, months | n (M/F) | Mean iron intake mg/day | % below EAR SD | EAR |
|---------------|----------------|---------------|-------|-------------|---------|-------------------------|----------------|-----|
| Spain [44]    | Yes            | FFQ + 24 h    | 1998–2000 | 24–60       | 367 (192/175) boys | 10.3k         | 9.0k |
| Spain [31]    | No             | FFQ + 24 h    | 2000c   | 7–12        | 75 (43/32) girls | 11.5          | 4.8  | 12.6 |
| Sweden [29]   | No             | 5 days DR     | 2003   | 12          | 82       boys | 9.1           | 2.7  | 12.6 |
| UKd [45, 46]  | Yes            | 3 days DR     | 1994–1996 | 18’         | 1,026 (563/463) boys | 5.5           | 2.0  | 46.0 |
| UKd, h [26, 91] | Yes            | 4 days WDR    | 2001–2003 | 6’         | 50 (25/25) boys | 6.9           | 2.8h | –    |
| UKc [47]      | Yes            | 4 days DR     | 2008–2010 | 18–47       | 219 (117/102) boys | 6.4           | 2.5  | 33.3 |
| UKd [32]      | ?              | 7 days WDR    | 1996–1998 | 4          | 152      boys | 5.0           | 3.8m | –    |
|               |                |               |         | 8          | 155      boys | 8.4           | 3.8  | 26.4 |
|               |                |               |         | 12         | 150      boys | 7.2           | 3.8  | 37.6 |
|               |                |               |         | 16         | 143      boys | 5.4           | 2.2  | 48.2 |
|               |                |               |         | 20         | 135      boys | 5.1           | 1.9  | 54.2 |
|               |                |               |         | 24         | 130      boys | 5.3           | 2.0  | 50.0 |

M = Male; F = female; EAR = estimated average requirement; 24 h = 24 hour recall; duplicate = duplicate sample method; DR = dietary record; WDR = weighted dietary record.

a Representative sample of the population of the country under study (assessed by original authors). b Year of food intake assessment. c Year of publication. Year of food intake assessment not reported. d Intake only from foods. e Intake from foods and supplements. f Participating children were recruited from hospitals. All had a normal eating pattern and none of the children had metabolic or gastrointestinal disorders. g Only non-breastfed infants. h Validation study that compared dietary intake from a food-frequency questionnaire with a 4-day weighed dairy. Only the results of the 4-day weighed dairy are presented as this method was considered the gold standard. i Children followed longitudinally over time. j Partially breastfed infants. k Standard deviation was not available from the publication and subsequently the percentage of children below the EAR could not be calculated. l Mean and standard deviation were not available from the publication and were therefore calculated from the median and percentiles (using the methods described by Hozo et al. [92]). m Mean values and pooled standard deviations were calculated from mean and standard deviation in subgroups.
Prevalence of Iron Deficiency Anaemia

The reported prevalence of IDA in infants and young children was below 5% in countries in Northern and Western Europe (i.e., Denmark [48], Germany [55], Iceland [24, 57, 58], Norway [60] and the United Kingdom [62, 65]) and in Spain [64], with the exception of one study conducted in Dutch children 6 months to 3 years that detected IDA in 8.5% of the children [67]. Reported prevalence rates were considerably higher in Eastern European countries. In Estonia [49], Greece [56] and in two studies performed in Turkey [52, 68], the prevalence of IDA was 9 to 16%, and estimated prevalence rates reached up to 50% in Albania [53] and in cow’s milk-fed infants in Turkey [51] (table 2). In the EURO-Growth study, a study in which IDA was assessed among 12-month-old infants in 11 European areas (Athens, Bilbao, Budapest, Dublin, Madrid, Naples, Porto, Rostock, Santiago, Umeå and Vienna) [63], IDA prevalence was on average 2.3% and ranged from 0 to 12% between study centres.

Discussion

Iron Intake

In most European countries, the mean iron intakes of infants and children aged 6–36 months were found to be
### Table 2. The prevalence of children aged 6–36 months with Iron Deficiency Anaemia (IDA) and Iron Deficiency (ID) in Europe

| Country [ref.] | Representative* | Yearb | Age, months | n   | Subgroup | Iron deficiency anaemia prevalence,% | criteria Hb, g/l | Iron deficiency prevalence, % | criteria SF, μg/l |
|----------------|------------------|-------|-------------|-----|----------|--------------------------------------|----------------|-----------------------------|----------------|
| Albania [53]   | No               | 2000  | 6–60        | 112 | BF       | 42                                   | 110; 10h        | 48                          | 10             |
| Denmark [48]   | No               | 2008–2009 | 9  | 278 | 0.7       | 100; 12                              |                | 7.8                        | 12             |
| Estonia [49]   | Yes              | 2004–2005 | 9–12   | 171 | BF §     | 9                                   | 105; 12          | 14                        | 12             |
| France [54]    | No               | 2002  | 16–18       | 13  | 178       | 85                                   | 105; 12          | 59                        | 12             |
|                |                  |       |             |    | 23        | 44                                   | 105; 12          | 27                        | 12             |
|                |                  |       |             |    | 323       |                                      |                |                            |                |
| France [50]    | No               | 1998  | 10          | 304 | Socially vulnerable | 26               | 105; 12          | 16                        | 12             |
|                |                  |       |             |    | At risk of vulnerability | 10               | 105; 12          | 10                        | 12             |
| Germany [55]   | No               | 2005–2006 | 4d | 53  | BF (0–4 months) | 0                  | 105; 12          | 6                          | 12             |
|                |                  |       |             |    | IF (0–4 months) | 0                  | 105; 12          | 4                          | 12             |
|                |                  |       |             |    | 33        | 19                                   | 105; 12          | 0                          | 12             |
|                |                  |       |             |    | 104       | 21                                   | 105; 12          | 0                          | 12             |
| Greece [56]    | No               | 2007c | 8–24        | 369 | 16        | 16                                   | 110; 10          | 34                        | 10             |
| Iceland [57]   | Yes              | 2003c | 12          | 114 | 2.7       | 105; 12                              |                | 41                        | 12             |
| Iceland [58]   | Yes              | 2004c | 24–30       | 71  | 1.4       | 105; 12                              |                | 27                        | 12             |
| Iceland [24]   | Yes              | 2006  | 12          | 138 | 0         | 105; 12                              |                | 6                         | 12             |
| Italy [59]     | ?                | 2000–2005 | 8d | 102 | BF       | 12                                   | 110; 12          | 15                        |                |
|                |                  |       |             |    | 63        | 15                                   | 110; 12          | 15                        |                |
|                |                  |       |             |    | 220       | 4                                    | 110; 12          | 15                        |                |
|                |                  |       |             |    | 12        | 8                                    | 110; 12          | 15                        |                |
|                |                  |       |             |    | 70        | 11                                   | 110; 12          | 15                        |                |
|                |                  |       |             |    | 72        | 3                                    | 110; 12          | 15                        |                |
|                |                  |       |             |    | 160       |                                      |                | 3                         |                |
| Netherlands [67] | No             | 2011–2012 | 6–36 | 400 | 8.5       | 110; 12                              |                | 19                        | 12             |
| Norway [60]    | No               | 1997  | 6d          | 278 | 2         | 110; 12                              |                | 4                         | 12             |
|                |                  |       |             |    | 12        | 5                                    | 110; 12          | 10                        | 12             |
|                |                  |       |             |    | 249       | 13                                   | 110; 12          | 12                        |                |
| Spain [64]     | No               | 2002c | 12          | 94  | 4.3       | 110; 12                              |                | 9.6                       |                |
| Sweden [29]    | No               | 2003  | 12          | 87  | 10        |                                        |                | 12                        |                |
| Turkey [68]    | No               | 2002c | 12–71       | 84  | 16        | 105; 16                              |                |                            |                |
| Turkey [51]    | No               | 2002–2006 | 6  | 240 | BF (exclusive) | 5.4                     | 110; 12          | 4.2                      | 12             |
|                |                  |       |             |    | 195       | 3.1                                   | 110; 12          | 12                        |                |
|                |                  |       |             |    | 177       | 25                                   | 110; 12          | 12                        |                |
| Turkey [52]    | No               | 2007c | 7           | 256 | 9.0       | 110; 10                              |                | 14                        | 10             |
| UK [62]        | Yes              | 1992–2003 | 18–54 | 727 | 3.4       | 110; 10                              |                | 31                        | 12             |
| UK [61]        | Yes              | 1993–2004 | 8d | 113 | BF h    | 5                                    | 110; 12          | 16                        |                |
|                |                  |       |             |    | 126       | 7                                    | 110; 12          | 16                        |                |
|                |                  |       |             |    | 687       | 2                                    | 110; 12          | 16                        |                |
|                |                  |       |             |    | 12        | 5                                    | 110; 12          | 16                        |                |
|                |                  |       |             |    | 102       | 5                                    | 110; 12          | 16                        |                |
|                |                  |       |             |    | 105       | 11                                   | 110; 12          | 16                        |                |
|                |                  |       |             |    | 574       | 3                                    | 110; 12          | 16                        |                |
| UK [65]        | Yes              | 1994  | 18          | 709 | 1.7       | 110; 12                              |                | 4                         | 12             |
close to the RDA. Nevertheless, high proportions of inadequate intakes were observed among both age categories, that is, up to 50% in infants between 6–12 months and up to 60% in children between 12 and 36 months (table 1). These data illustrate that a mean intake above the RDA does not necessarily reflect a low prevalence of inadequacy. The evaluation of the dietary reference values for iron is complicated by the fact that the distribution of iron requirements is asymmetrical [69]. This is reflected in the great variety of reference values that have been proposed for iron by different authorities. Similarly to a recent study of ILSI Europe [16], we used the EARs set by the UK Committee on Medical Aspects of Food Policy [17]. The fact that a very high proportion (up to 50% of 6–12 month olds and up to 60% of 12–36 month olds) have inadequate iron intakes while only a smaller proportion of children have ID (up to 25% of 6–12 month olds and up to 48% of 12–36 month olds), leads us to the question whether the requirements have been estimated too high. Although the RDA proposed by the UK Committee on Medical Aspects of Food Policy is similar to the one proposed by the US Institute of Medicine [19] (6.9 mg/day vs. 7 mg/day), the EAR is markedly higher (5.3 mg/day vs. 3 mg/day). European alignment of reference values for infants and young children based on the latest scientific data is urgently needed.

| Country [ref.] | Representativea | Yearb | Age, months | n   | Subgroup | Iron deficiency anaemia prevalence, % | Iron deficiency criteria Hb, g/l; SF, μg/l |
|----------------|-----------------|-------|-------------|-----|----------|--------------------------------------|------------------------------------------|
| UK [32]        | ?               | 1996–2008 | 4           | 85  |          | 0                                    | 10                                      |
|                |                 | 12     | 92          |     |          | 4.2                                  | 10                                      |
|                |                 | 24     | 101         |     |          | 2.8                                  | 10                                      |
| UK [66]        | Yes             | 2004c  | 13          | 414 | boys     | 3.1                                  | 110b                                   |
|                |                 |        |             |     | girls    | 1.3                                  | 110b                                   |
| Europe [63]    | Yes             | 1992–2004 | 12         | 261 |          | 7.7                                  | 10                                      |
|                |                 |         | 24          | 227 |          | 18                                   | 10                                      |
|                |                 |         |             |     |          | 13                                   | 10                                      |

Hb = Haemoglobin; SF = serum ferritin; BF = breast fed; CM = cow’s milk; FM = formula milk.

a Representative sample of the population of the country under study (assessed by original authors). b Year of iron status assessment. c Year of publication. d Year of iron level measurement not reported. e Children followed longitudinally over time. f BF, children who were currently receiving human milk; SCM, children who were currently receiving semi-skimmed cow’s milk; WCM, children who were currently receiving whole cow’s milk; FM, children who were currently receiving iron-fortified formula milk. g Based on family income estimation and status. h BF, children who were predominantly breast fed for the first 4 months of life; IF, children who were predominantly iron-fortified infant formula fed for the first 4 months of life. i SF <10 μg/l or the combination of mean cell volume <70 fl and red cell distribution width >14.5%. j Plus mean cell volume <74 fl. k Hb <110 g/l plus two or more abnormal iron indicators out of four (SF <10 μg/l, MCV <70 fl, transferrin saturation <10%, serum transferrin receptor concentration >4.4 mg/l).

As this review is based on published studies, we did not have access to the raw data and therefore, all estimated prevalence rates for inadequate intake are based on published values (mean and standard deviation). Subsequently, the presented estimates are less accurate than would have been the case if raw data had been available. Yet, in a study for which we had raw data [43], there was only a small difference between the estimated percentage of children with iron intakes below the RDA using published data (14.3%) and the percentage calculated using the raw data (12.5%). Another limitation was that in the studies in our review no information was available on the form of iron (haem or non-haem iron) or the presence of inhibitors and enhancers of iron absorption in the diet, which are important factors in determining the bioavailability of iron.
Iron Deficiency

When comparing the prevalence of ID between the studies, large variations in study results were observed. This is, at least partly, due to the problem that no consensus exists on the criteria for the diagnosis of ID and in different studies different cut-off values were used to define ID. For example, a number of studies used the stricter cut-off level for SF of 10 μg/l [32, 52, 53, 56, 63, 66] to define iron deficiency (vs. only two studies that used a higher cut-off level [59, 61]). Nevertheless, the results confirm that ID is common in countries in Europe (table 2). The prevalence rates probably would even be a few percentages higher if the SF >12 μg/l cut-off would have been applied in all studies. Two to 25% of infants aged 6–12 months were found to be iron deficient, with a higher prevalence in infants who were socially vulnerable and infants consuming cow’s milk as a main drink in their first year of life. In children of 12–36 months, the reported prevalence rates of ID varied between 3 and 48%. These huge variations are most likely explained by the age of the children under study, the year of study performance and country differences as in the social economic status, ethnicity and the use of iron-rich or fortified complimentary foods and drinks. Several studies found a positive association between (red) meat, fruit and vegetable intake and iron status in young children [24, 62, 65, 72], and a recent meta-analysis in 2–5 year old children showed clear effects of iron supplementation on Hb and SF response [73]. Also differences in the use of foods that have a negative impact on iron status, such as dairy products (containing calcium), high-fibre foods (containing phytates) and tea and coffee (containing polyphenols) may contribute to variations between countries in the prevalence of ID [74].

Of the studies performed in the United Kingdom, the only study with a very high prevalence of ID (31%) was conducted in 1992–1993. These were the years that the bovine spongiform encephalopathy (BSE) crisis reached its peak in the United Kingdom and the consumption of beef, an important source of iron, fell by 25% [75]. However, although the iron intake of young children has improved with an increase in mean intake from 4.9 mg/day in 1992–1993 [76] to 6.4 mg/day in 2008–2010 [47], iron intake is still lower than the recommended amount and 33% of children has an intake below the EAR.

Iron Deficiency Anaemia

Similar to the ID prevalence rates, the reported prevalence rates for IDA varies greatly between countries and between studies. IDA prevalence was generally below 5% in Northern and Western European countries, whereas it reached 50% in some countries and populations in Eastern Europe (table 2). The higher prevalence of IDA in Eastern Europe can at least partly be explained by the fact that in many, especially rural parts of Eastern Europe, cow’s milk is an important part of the diet of infants below 1 year of age, and iron-fortified milk and cereals are not often consumed in this age group [77]. Moreover, other conditions presenting with low SF and Hb levels such as β-thalassemia syndromes, are much more common in these regions than in the Western and Northern parts of Europe. For example, the reported prevalence of haemoglobinopathy gene carriers is 7–10% in Turkey, compared to only 0.5–1% in Germany [78]. Although the prevalence of IDA is relatively low in large parts of Europe, iron deficiency in infants and young children is still a public health priority as children with depleted iron stores but without anaemia at 1 year of age might have lower fine motor and mental development scores in later childhood than children with sufficient iron stores [10, 79–83]. On the other hand, it has been suggested that supplemental iron in infants with high Hb levels may adversely affect neurodevelopmental outcome [84]. Defining optimal amounts of iron in iron-fortified milk and foods is therefore of upper most importance.

A number of studies included in our review confirmed that the consumption of cow’s milk in the infant and child diet is an important predictor of iron status [54, 60]. The low iron content in cow’s milk is likely the most important cause of this association [85]. Thane et al. reported that children consuming more than 400 ml of milk (all types) per day, which is recommended in this age group to ensure a sufficient supply of calcium and B-vitamins, were less likely to consume iron-rich complementary foods, like meat, fish, fruit and nuts, and these children were more at risk to have a poor iron status [62]. Moreover, cow’s milk is rich in calcium and casein, both known to inhibit iron absorption [85]. Other studies showed that late weaning, and particularly the late introduction of iron-rich meat, is an important predictor of iron deficiency in children older than 1 year [86, 87].

Conclusions and Areas for Further Research

In conclusion, we showed that mean iron intakes of infants and children aged 6 to 36 months in most European countries are close to the RDA. Nevertheless, high proportions of inadequate intakes and high prevalence rates of ID were observed. IDA is especially common in Eastern Europe where up to half of the children are affected, while the prevalence in Western and Northern Europe is generally below 5%.
Several European countries, such as Norway, Portugal and Switzerland, lack national data on infants’ and children’s iron intake, although these data are needed to determine compliance with daily recommended iron levels and to assess the risk of inadequate intake. Moreover, surveys are often out of date, data are not always collected using the preferred method [88] and there is a scarcity of data on national prevalence of ID and IDA in infants and children; many studies that reported on the prevalence of ID or IDA focused on limited geographical areas that are not necessarily representative of the entire country.

Further research should focus on accurately establishing iron requirements in young children and identifying the components in a young child’s diet that are especially contributing to (high) iron intakes and an appropriate iron status. Sophisticated analytical methods should be applied to associate the effects of iron intake (haem and non-haem iron) and contributing dietary factors with iron status. Insight in these components of the diet of children younger than 36 months may contribute to improved dietary guidelines for these children ensuring adequate amounts of iron in the diet and body stores. Moreover, the relationship between maternal ID/IDA and their infants’ iron status and development warrants further study. Several studies have demonstrated that effects of pregnant women’s iron status on infant iron status are more apparent in later infancy than in the newborn period [89, 90].

Health programs should (keep) focus(ing) on iron malnutrition by educating parents on food choices for their children with iron rich and iron fortified foods, and where iron intakes are lowest, encourage iron supplementation programmes.

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References

1 FAO/WHO: Human Vitamin and Mineral Requirements. Chapter 13: Iron. Geneva, 2002.
2 Andrews NC, Levy JE: Iron is hot: an update on the pathophysiology of hemochromatosis. Blood 1998;92:1845–1851.
3 Dewey KG, Chaparro CM: Session 4: mineral metabolism and body composition iron status of breast-fed infants. Proc Nutr Soc 2007;66:412–422.
4 Butte NF, Lopez-Alarcon MG, Garza C: Nutrient Adequacy of Exclusive Breastfeeding for the Term Infant during the First Six Months of Life. Geneva, WHO, 2001.
5 Domellof M, Lönnerdal B, Abrams SA, Hearnell O: Iron absorption in breast-fed infants: effects of age, iron status, iron supplements, and complementary foods. Am J Clin Nutr 2002;76:198–204.
6 Domellof M: Iron requirements in infancy. Ann Nutr Metab 2011;59:59–63.
7 WHO/FAO: Guidelines on Food Fortification with Micronutrients. Geneva, 2006.
8 WHO/UNICEF/UNU: Iron Deficiency Anaemia – Assessment, Prevention, and Control. A Guide for Programme Managers. Geneva, 2001.
9 Lozoff B: Iron deficiency and child development. Food Nutr Bull 2007;28(suppl 4):S560–S571.
10 Akman M, Cebeci D, Okur V, Angin H, Aballi O, Akman AC: The effects of iron deficiency on infants’ developmental test performance. Acta Paediatr 2004;93:1391–1396.
11 Aggett PJ, Agostoni C, Axelson I, Bresson JL, Goulet O, Hearnell O, et al: Iron metabolism and requirements in early childhood: do we know enough?: a commentary by the ESPGHAN Committee on Nutrition. J Pediatr Gastroenterol Nutr 2002;34:337–345.
12 Bourre JM: Effects of nutrients (in food) on the structure and function of the nervous system: update on dietary requirements for brain. Part 1:micronutrients. J Nutr Health Aging 2006;10:377–385.
13 Gordon N: Iron deficiency and the intellect. Brain Dev 2003;25:3–8.
14 Alles M, Eussen S, Ake-Tano O, Dionf S, Tan-ya A, Eussen S, et al: Situational analysis and expert evaluation of the nutrition and health status of infants and young children in five countries in sub-Saharan Africa. Food Nutr Bull 2013;34:287–298.
15 Roman Vinas B, Ribas Barba L, Ngo J, Gurinovic M, Novakovic R, Cavelaars A, et al: Projected prevalence of inadequate nutrient intakes in Europe. Ann Nutr Metab 2011;59:84–95.
16 Mensink GB, Fletcher R, Gurinovic M, Huybrechts I, Lafay L, Serra-Majem L, et al: Mapping low intake of micronutrients across Europe. Br J Nutr 2013;110:755–773.
17 Committee on Medical Aspects of Food Policy: Dietary Reference Values of Food Energy and Nutrients for the United Kingdom. Report on Health and Social Subjects, 1991.
18 Joint FAO/WHO Expert Consultation on Human Vitamin and Mineral Requirements: Vitamin and Mineral Requirements in Human Nutrition. Geneva, 2004.
19 Panel on Micronutrients, Food and Nutrition Board, Institute of Medicine: Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc. Washington, DC, 2001.
20 Doets EL, Cavelaars AE, Dhoukse-Rutten RA, van ’t Veer P, de Groot LC. Explaining the variability in recommended intakes of folate, vitamin B12, iron and zinc for adults and elderly people. Public Health Nutr 2012;15:906–915.
21 Cavelaars AE, Doets EL, Dhoukse-Rutten RA, Hermoso M, Fairweather-Tait SJ, Koletzko B, et al: Prioritizing micronutrients for the purpose of reviewing their requirements: a protocol developed by EURRECA. Eur J Clin Nutr 2010;64(suppl 2):S19–S30.

Eussen/Alles/Uijterschout/Brus/
vanderHorst-Graat
Iron Intake and Status of European Children

Iron nutrition plays a crucial role in the development of children, and it is essential to ensure that their iron intakes are adequate. This is particularly important for infants and young children, who are at greatest risk of iron deficiency. A recent study aimed to assess iron status in 1 to 18 year old German children and adolescents. The results indicated that 18% of the children were iron deficient, a prevalence that is consistent with reports from other European countries.

Nutrition and iron status are influenced by various factors, including dietary intake, genetics, and health conditions. For instance, a study on food frequency and nutrient intakes of non-breastfed French children of less than 36 months of age revealed that the main sources of iron were meat and meat products, followed by dairy products and vegetables. The study also found that the iron intake of children aged 1 to 6 years was below the Adequate Intake (AI) for this age group.

In conclusion, maintaining adequate iron intakes in children is crucial for their growth and development. Health professionals should continue to monitor iron status in children and work to ensure that their intakes are sufficient to prevent iron deficiency.

References:
Kersting M, Alexy U, Sichert-Hellert W: Dietary intake and food sources of minerals in 1 to 18 year old German children and adolescents. Nutr Res 2001;21:607–616.
Sichert-Hellert W, Kersting M, Manz F: Changes in time-trends of nutrient intake from fortified and non-fortified food in German children and adolescents – 15 year results of the DONALD study. Dortmund Nutritional and Anthropometric Longitudinally Designed Study. Eur J Nutr 2001;40:49–55.
Ocke MC, et al: Dutch National Food Consumption Survey – Young Children 2005/2006. Biljoen J: National Institute for Public Health and the Environment (RIVM).
Irish Universities Nutrition Alliance: National Pre-School Nutrition Survey. Summary Report on: Food and Nutrient Intakes, Physical Measurements and Barriers to Healthy Eating, 2012.
Sțopan L, Stos K, Oltarzewska MG: Dietary supplements in diet of children and adolescents [Suplementy diety w zywieniu dzieci i młodzieży]. Pediatria Wspolczesna 2007;9:41–44.
Weker H, Baranska M, Dylag H, Riahi A, Wiech M, Strucinska M, Kurpinska P, et al: Analysis of nutrition of children aged 13–36 months of age in Poland: a nation-wide study. Med Wieku Rozwoju 2011;15:224–231.
Serra-Majem L, Ribas-Barba L, Perez-Rodrigo C, Barrina JA: Nutrient adequacy in Spanish children and adolescents. Br J Nutr 2006;96(suppl 1):S49–S57.
Emmett P, Rogers I, Symes C; ALSAPAC Study Team, Avon Longitudinal Study of Pregnancy and Childhood: Food and nutrient intakes of a population sample of 3-year-old children in the south west of England in 1996. Public Health Nutr 2002;5:55–64.
Gowin I, Emmett P; ALSAPAC Study Team: Diet in a group of 18-month-old children in South West England, and comparison with the results of a national survey. J Hum Nutr Diet 2007;20:254–267.
National Diet and Nutrition Survey: Years 1 and 2 of Rolling Program, 2008–2010. London, NatCen, UCL, MRC, 2011.
Gondolf UH, Tetens I, Michaelsen KF, Trolle E: Iron supplementation is positively associated with increased serum ferritin levels in 9-month-old Danish infants. Br J Nutr 2013;109:103–110.
Vendt N, Grunberg H, Leedo S, Tíllmann V, Talvik T: Prevalence and causes of iron deficiency anemia in infants aged 9 to 12 months in Estonia. Medicina (Kaunas) 2007;43:947–952.
"Tone MD, Vincet C: Socioeconomic status and child health: the experience of the París Child Health Checkup Center [Precarita et sante en pediatrie: experience du centre de bilans de sante de l’enfant]. Arch Pediatr 2009;7:1274–1283.
Polat TB, Sara EU, Urganci N, Akildiz B, Cemelmi F: Evaluation of iron status in relation to feeding practices in early infancy. Medad J Child 2011;47:70–74.
Turgut S, Polat A, Inan M, Turgut G, Emmgnigil G, Bican M, et al: Interaction between anemia and blood levels of iron, zinc, copper, cadmium and lead in children. Indian J Pediatr 2007;74:827–830.
Buonomo E, Cenko F, Altan AM, Gado A, Marazzi MC, Palombi L: Iron deficiency anemia and feeding practices in Albanian children. Ann Ig 2005;17:27–33.
Vincet C, Foucault C: [Measuring iron levels relative to the type of milk consumed with in a population of 16 to 18 month old French infants]. Sante Publique 2005;17:339–346.
Dube K, Schwartz J, Mueller MJ, Kalhoff H, Kersting M: Iron intake and iron status in breastfed infants during the first year of life. Clin Nutr 2010;29:773–778.
Gompakis N, Economou M, Tsantali C, Kouloulis V, Keramida M, Athanasiou-Metaxa M: The effect of dietary habits and socio-economic status on the prevalence of iron deficiency in children of northern Greece. Acta Paediatr 2007;96:100–204.
Thorsdottir I, Gunnarsson BS, Atladottir H, Michaelsen KF, Palsson G: Iron status at 12 months of age – effects of body size, growth and diet in a population with high birth weight. Eur J Clin Nutr 2003;57:505–513.
Gunnarsson BS, Thorsdottir I, Palsson G: Iron status in 2-year-old Icelandic children and associations with dietary intake and growth. Eur J Clin Nutr 2004;58:901–906.
Capozzi L, Russo B, Bertocco F, Ferrara D, Ferrara M: Diet and iron deficiency in the first year of life: a retrospective study. Hematology 2010;15:410–413.
Hay G, Sandstad B, Whiteall A, Borch-Johnsen B: Iron status in a group of Norwegian children aged 6–24 months. Acta Paediatr 2004;93:592–598.
Hopkins D, Emmett P, Steer C, Rogers I, Noble S, Emond A: Infant feeding in the second 6 months of life related to iron status: an observational study. Arch Dis Child 2007;92:850–854.
Thane CW, Walmsley CM, Bates Cj, Prentice A, Cole Tj: 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 2000;3:433–440.
Malin C, Persson LA, Freeman V, Guerra A, van’t Hof MA, Haschke F, et al: Prevalence of iron deficiency in 12–mo-old infants from 11 European areas and influence of dietary factors on iron status (Euro-Growth study). Acta Paediatr 2001;90:492–498.
Dura Trave T, Duz Velaz L: [Prevalence of iron deficiency in healthy 12–onth-old infants]. Ann Esp Pediatr 2002;57:209–214.
Gowin I, Emond A, Emmett P; ALSAPAC Study Group: Association between composition of the diet and haemoglobin and ferritin levels in 18-month-old children. Eur J Clin Nutr 2001;55:278–286.
Wright CM, Kelly J, Trail A, Parkinson KN, Summerfield G: The diagnosis of borderline iron deficiency: results of a therapeutic trial. Arch Dis Child 2004;89:1028–1031.
[References]

67 Uijterschout L, Vloemans J, Vos R, Teunisse PP, Hudig C, Bubbers S, et al: Prevalence and risk factors of iron deficiency in healthy young children in the southwestern Netherlands. J Pediatr Gastroenterol Nutr 2014;58:193–198.

68 Kilinc M, Yuregir GT, Ekerbicer H: Anaemia and iron-deficiency anaemia in south-east Anatolia. Eur J Haematol 2002;69:280–283.

69 Carriquiry AL: Assessing the prevalence of nutrient inadequacy. Public Health Nutr 1999;2:23–33.

70 Gibson SA: Iron intake and iron status of preschool children: associations with breakfast cereals, vitamin C and meat. Public Health Nutr 1999;2:521–528.

71 Serra-Majem L: Vitamin and mineral intakes in European children. Is food fortification needed? Public Health Nutr 2001;4:101–107.

72 Engelmann MD, Sandstrom B, Michaelsen KF: Meat intake and iron status in late infancy: an intervention study. J Pediatr Gastroenterol Nutr 1998;26:26–33.

73 Thompson J, Biggs BA, Pasricha SR: Effects of daily iron supplementation in 2- to 5-year-old children: systematic review and meta-analysis. Pediatrics 2013;131:739–753.

74 Fairweather-Tait SJ: Iron nutrition in the UK: getting the balance right. Proc Nutr Soc 2004;63:519–528.

75 Thankappan S, Flynn A: Exploring the UK Red Meat Supply Chain. Cardiff, The Centre for Business Relationships, Accountability, Sustainability and Society, 2006.

76 Gregory JR, Collins DL, Davies PSW, Hughes JM, Clarke PC: National Diet and Nutrition Survey: Children Aged 1½ to 4½ Years. London, HMSO, 1995.

77 Numsight: Global report Milks Usage and Attitude Research. TNS for Danone Baby Nutrition, 2011.

78 Kohne E: Hemoglobinopathies: clinical manifestations, diagnosis, and treatment. Dtsch Arztebl Int 2011;108:532–540.

79 Gunnarsson BS, Thorsdottir I, Palsson G, Grettisson SJ: Iron status at 1 and 6 years versus developmental scores at 6 years in a well-nourished affluent population. Acta Paediatr 2007;96:391–395.

80 Oski FA, Honig AS, Helu B, Howanitz P: Effect of iron therapy on behavior performance in nonanemic, iron-deficient infants. Pediatrics 1983;71:877–880.

81 Pollitt E, Saco-Pollitt C, Leibel RL, Viteri FE: Iron deficiency and behavioral development in infants and preschool children. Am J Clin Nutr 1986;43:555–565.

82 Sachdev H, Gera T, Nestel P: Effect of iron supplementation on mental and motor development in children: systematic review of randomised controlled trials. Public Health Nutr 2005;8:117–132.

83 Shafir T, Angulo-Barroso R, Jing Y, Angelilli ML, Jacobson SW, Lozoff B: Iron deficiency and infant motor development. Early Hum Dev 2008;84:479–485.

84 Lozoff B, Castillo M, Clark KM, Smith JR: Iron-fortified vs low-iron infant formula: developmental outcome at 10 years. Arch Pediatr Adolesc Med 2012;166:208–215.

85 Ziegler EE: Consumption of cow’s milk as a cause of iron deficiency in infants and toddlers. Nutr Rev 2011;69(suppl 1):S37–S42.

86 Sultan AN, Zuberi RW: Late weaning: the most significant risk factor in the development of iron deficiency anemia at 1–2 years of age. J Ayub Med Coll Abbottabad 2003;15:3–7.

87 Requejo AM, Navaia B, Ortega RM, Lopez-Sobaler AM, Quintas E, Gaspar MJ, et al: The age at which meat is first included in the diet affects the incidence of iron deficiency and ferrropenic anaemia in a group of pre-school children from Madrid. Int J Vitam Nutr Res 1999;69:127–131.

88 European Food Safety Authority (EFSA): General principles for the collection of national food consumption data in the view of a pan-European dietary survey. Parm, EFSA Journal, 2009, p 1435.

89 Kilbride J, Baker TG, Parapia LA, Khoury SA, Shuqaidef SW, Jerwood D: Anaemia during pregnancy as a risk factor for iron-deficiency anaemia in infancy: a case-control study in Jordan. Int J Epidemiol 1999;28:461–468.

90 Shao J, Lou J, Rao R, Georgieff MK, Kaciroti N, Felt BT, et al: Maternal serum ferritin concentration is positively associated with newborn iron stores in women with low ferritin status in late pregnancy. J Nutr 2012;142:2004–2009.

91 Marriott LD, Robinson SM, Poole J, Borland SE, Godfrey KM, Law CM, et al: What do babies eat? Evaluation of a food frequency questionnaire to assess the diets of infants aged 6 months. Public Health Nutr 2008;11:751–756.

92 Hozo SP, Djulbegovic B, Hozo I: Estimating the mean and variance from the median, range, and the size of a sample. BMC Med Res Methodol 2005;5:13.