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

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Iron · Child · Infant · Review · Nutrient · Food · Diet · Toddler · Anaemia

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:*** Computerized 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

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[2]. However, considerable amounts of iron must be provided by the diet to replace the iron that is lost from the body (through blood loss and exfoliation of skin and gastrointestinal cells) and the iron that is required for growth [1]. Healthy, full-term, normal birth weight infants are born with sufficient stores of iron to cover their needs during the first 4–6 months of life [3, 4]. After the age of 6 months, infants' iron reserves are depleted and the child becomes critically dependent on dietary iron [1, 3–5]. Since daily iron requirements (in mg/kg) are higher during late infancy and early childhood than during any other period of life [6], and many young children do not consume large quantities of iron-rich foods such as red meat and green leafy vegetables, young children are especially at risk of inadequate intakes of iron [7]. Inadequate dietary intakes of iron may lead to a depletion of body's iron stores or iron deficiency (ID) that, if not reversed, may progress to iron deficiency anaemia (IDA). ID and IDA are the most severe and prevalent nutritional deficiencies in the world, affecting both developing as well as industrialized countries [8]. Increasing evidence suggests that ID, with or without anaemia, may have a long-term detrimental influence on mental and psychomotor development [9, 10]. The less efficient supply of oxygen to the brain and the decreased brain energy production, together with the effects of iron deficiency on myelination and neurotransmitter function, are considered to be the most important mechanisms explaining the association between iron deficiency and impaired neurodevelopment [11, 12]. Young children are particularly vulnerable to the effects of iron deficiency because the first three years of life is a period of rapid growth and development of the brain and nervous system [13].

Especially in developing countries, it is well known that iron deficiency remains the most common nutritional deficiency in the world. In developed countries, among others Europe, the situation is less clear-cut. Although many studies have evaluated iron intake and status among infants and young children in Europe, to our knowledge, no systematic review of published literature has been conducted.

Therefore, we aimed to review the prevalence of inadequate iron intake and the prevalence of iron deficiency (anaemia) in European children aged 6 to 36 months.

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*, ferrous, ferric, ferritin, anemi*, anaemi*, hemoglobin or haemoglobin combined to intake*, diet*, supplement*, status, deplet*, deficien*, concentration* or level* and infan*, 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 RECommendations Aligned (EURRECA) Network of Excellence [15]. In short, the EAR cut-point is calculated as follows: $z = (x - \mu)/SD$, where x is the EAR, μ 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

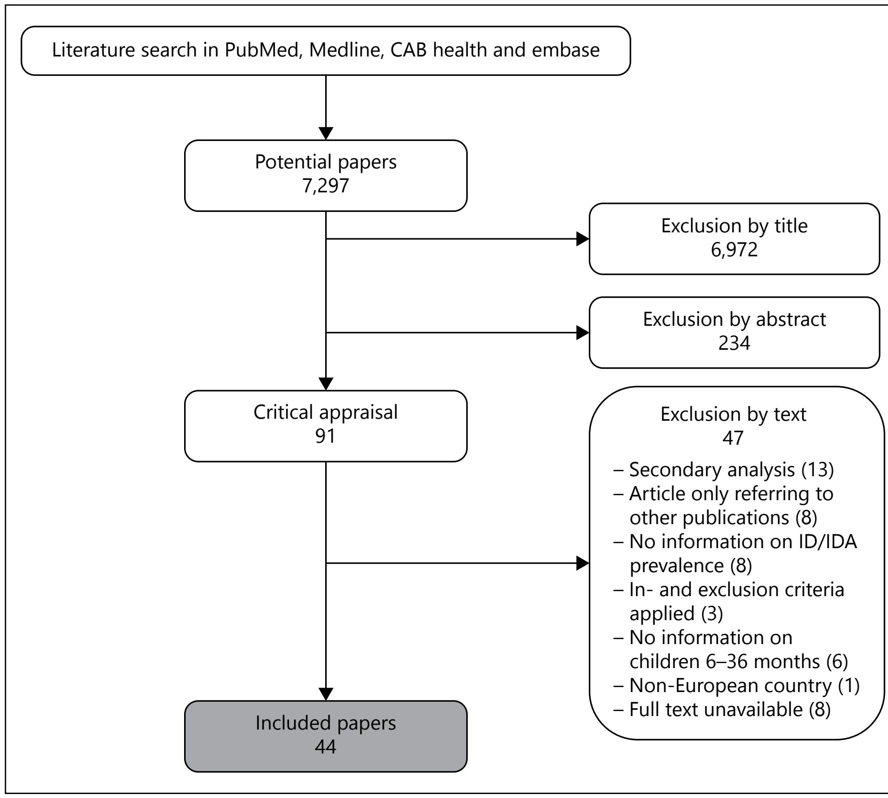

Fig. 1. Literature search and selection.

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.]	Representative[a]	Intake method	Year[b]	Age, months	n (M/F)		Mean iron intake mg/day	SD	% below EAR
Austria [33]	Yes	3 × 24 h	2006	12–36	183 (83/100)		5.3	2.9	50.0
Belgium[d, f] [34]	No	7 days duplicate	1999–2000	24–47	115		4.8	2.0	59.9
Belgium[d] [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
France[d, g] [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
Finland[e] [36, 37]	Yes	3 days DR	2003–2004	12–23	455[g] (257/198)	boys	6.7	2.3	27.1
						girls	6.2	2.9	37.8
				12–23	112[j] (55/57)	boys	5.2	2.1	51.9
						girls	4.7	1.7	63.8
				24–35	230 (112/118)	boys	6.0	2.5	39.0
						girls	5.7	1.9	41.7
Germany[d] [38]	Yes	3 days WDR	1985–1989	12–47	105		5.6	2.1[l]	10.9
Germany[d] [39]	Yes	3 days WDR	1986–2000	24–47	916		5.8	1.6	4.0
Germany[d, g] [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
				12–23	168 (81/87)	boys	5.9	2.8	41.5
						girls	5.8	3.1	43.6
				24–35	174 (89/85)	boys	6.7	3.2	33.1
						girls	6.0	2.6	39.4
Netherlands[e] [40]	Yes	2 days DR	2005–2006	24–35	640 (327/313)	boys	6.6	1.6[l]	20.2
						girls	6.4	1.8[l]	26.8
Netherlands[e] [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
Iceland[e] [24]	Yes	3 days WDR	2005–2006	9[i]	122	boys	6.3	3.2	46.3
						girls	6.3	2.7	45.6
				12	110	boys	6.8	4.0	42.1
						girls	5.8	2.0	54.0
Ireland[e] [41]	Yes	3 days DR	2012	12–23	126		7.0	3.0	28.6
				24–35	124		7.6	3.2	23.6
Poland[e] [42]	?	24 h	2000	12–47	118 (70/48)	boys	5.4		
						girls	4.9		
Poland[e, g] [28]	Yes	24 h	2006[c]	6	43		9.7	2.8	–
				12	56		7.7	2.9	27.9
Poland[e] [43]	Yes	3 days DR	2010	13–36	400 (222/178)		8.5	3.0	14.3

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Table 1. (continued)

Country [ref.]	Representative[a]	Intake method	Year[b]	Age, months	n (M/F)		Mean iron intake mg/day	SD	% below EAR
Spain [44]	Yes	FFQ + 24 h	1998–2000	24–60	367 (192/175)	boys girls	10.3[k] 9.0[k]		
Spain [31]	No	FFQ + 24 h	2000[c]	7–12	75 (43/32)		11.5	4.8	12.6
Sweden [29]	No	5 days DR	2003	12	82	boys girls	9.1 8.8	2.7 2.4	12.6 12.2
UK[d] [45, 46]	Yes	3 days DR	1994–1996	18[i]	1,026 (563/463)	boys girls	5.5 5.2	2.0 1.7	46.0 52.4
				43	863 (488/375)	boys girls	6.4 6.0	1.7 1.9	25.9 34.4
UK[d, h] [26, 91]	Yes	4 days WDR	2001–2003	6[i] 12	50 (25/25) 50 (27/23)		6.9 5.2	2.8[l] 2.5[l]	– 62.5
UK[e] [47]	Yes	4 days DR	2008–2010	18–47	219 (117/102)		6.4	2.5	33.3
UK[d] [32]	?	7 days WDR	1996–1998	4 8 12 16 20 24	152 155 150 143 135 130		5.0 8.4 7.2 5.4 5.1 5.3	3.3[m] 3.8 3.8 2.2 1.9 2.0	– 26.4 37.6 48.2 54.2 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.

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 socioeconomic 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]. 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].

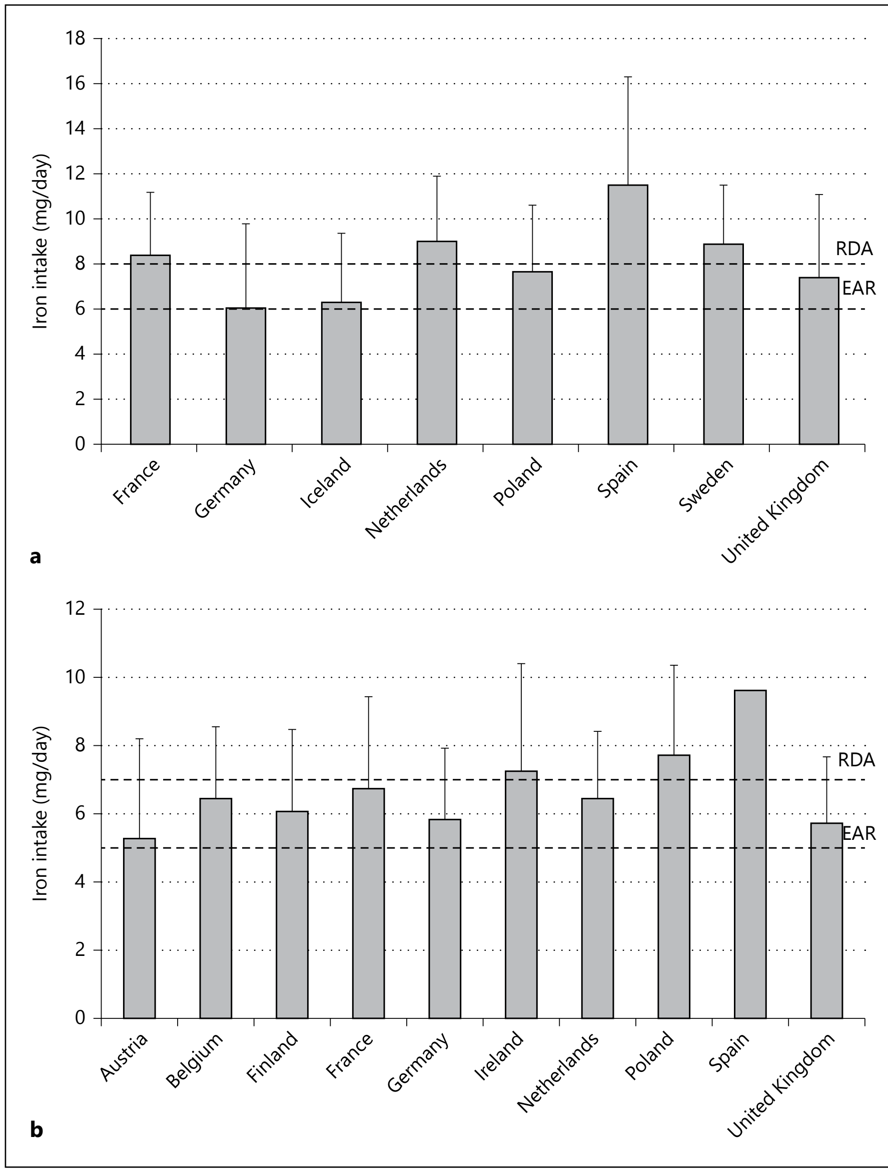

Fig. 2. Average iron intakes (mg/day) in infants aged 6–12 months (**a**) and young children aged 12–36 months (**b**) in different European countries, compared to the estimated average requirement (EAR) and the recommended dietary allowance (RDA). The error bars represent the pooled standard deviation of the included studies (see table 1).

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[a]	Year[b]	Age, months	n	Subgroup	Iron deficiency anaemia		Iron deficiency	
						prevalence, %	criteria Hb, g/l; SF, μg/l	prevalence, %	criteria SF, μg/l
Albania [53]	No	2000	6–60	112		42	110; 10[i]	48	10
Denmark [48]	No	2008–2009	9	278		0.7	100; 12	7.8	12
Estonia [49]	Yes	2004–2005	9–12	171		9	105; 12[j]	14	12
France [54]	No	2002	16–18	13	BF[e]			85	12
				178	SCM			59	12
				23	WCM			44	12
				323	FM			27	12
France [50]	No	1998	10	304	Socially vulnerable[f]			26	12
				463	At risk of vulnerability			16	12
				1,142	Standard			10	12
Germany [55]	No	2005–2006	4[d]	53	BF (0–4 months)[g]	0	105; 12	6	12
				23	IF (0–4 months)	0	105; 12	4	12
			7	53	BF (0–4 months)	4	105; 12	19	12
				23	IF (0–4 months)	0	105; 12	0	12
			10	53	BF (0–4 months)	2	105; 12	21	12
				23	IF (0–4 months)	0	105; 12	0	12
Greece [56]	No	2007[c]	8–24	369		16	110; 10	34	10
Iceland [57]	Yes	2003[c]	12	114		2.7	105; 12[j]	41	12
Iceland [58]	Yes	2004[c]	24–30	71		1.4	105; 12[j]	27	12
Iceland [24]	Yes	2006	12	138		0	105; 12[j]	6	12
Italy [59]	?	2000–2005	8[d]	102	BF			12	15
				63	CM			15	15
				220	FM			4	15
			12	70	BF			8	15
				72	CM			11	15
				160	FM			3	15
Netherlands [67]	No	2011–2012	6–36	400		8.5	110; 12	19	12
Norway [60]	No	1997	6[d]	278		2	110; 12	4	12
			12	249		5	110; 12	10	12
			24	229		5	110; 12	13	12
Spain [64]	No	2002[c]	12	94		4.3		9.6	
Sweden [29]	No	2003	12	87				10	12
Turkey [68]	No	2002[c]	12–71	84		16	105; 16		
Turkey [51]	No	2002–2006	6	240	BF (exclusive)	5.4	110; 12	4.2	12
				195	FM/BF	8.7	110; 12	3.1	12
				177	CM/BF	53	110; 12	25	12
Turkey [52]	No	2007[c]	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	8[d]	113	BF[h]			5	16
				126	CM			7	16
				687	FM			2	16
			12	102	BF[h]			5	16
				105	CM			11	16
				574	FM			3	16
UK [65]	Yes	1994	18	709		1.7	110; 12	4	12

Table 2. (continued)

Country [ref.]	Representative[a]	Year[b]	Age, months	n	Subgroup	Iron deficiency anaemia		Iron deficiency	
						prevalence, %	criteria Hb, g/l; SF, µg/l	prevalence, %	criteria SF, µg/l
UK [32]	?	1996–2008	4	85				0	10
			12	92				4.2	10
			24	101				2.8	10
UK [66]	Yes	2004[c]	13	414				7.7	10
Europe [63]	Yes	1992–2004	12	261	boys	3.1	110[k]	18	10
				227	girls	1.3	110[k]	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. Year of iron level measurement not reported. [d] Children followed longitudinally over time. [e] 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. [f] Based on family income estimation and status. [g] 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. [h] BF, children who received human milk (with or without some cow's milk but no formula) at 8 months of age; CM, children who received only cow's milk at 8 months of age; FM, children who received iron-fortified formula milk (with or without some human and/or cow's milk) at 8 months of age. [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).

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.

Large differences were observed in the prevalence of inadequate intake between and within countries, depending on differences in age and gender of the studied children, and on country-specific factors, such as the voluntary or mandatory iron fortification of flour and breakfast cereals, and the use of follow-on or young-child formula fortified with iron. For example, the use of iron-fortified breakfast cereals have been shown to be positively associated with iron intake in infants and young children in France, Ireland, United Kingdom and Spain [70, 71]. Moreover, various methods for assessing iron intake have been used in different countries, for example, some surveys used a single 24-h recall to measure iron intake, whereas others used a 3- or 7-day (weighted) dietary record (table 1).

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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