Submitted in partial fulfilment of the requirements for the Degree of Bachelor of Science

Dietary Reference Values for Iron and Actual Iron Intake in Primary School-age Children: A Systematic Review

May 2025

Abstract

Background: Children's diets are important in determining their future development and health. Adequate iron intake is especially important for primary school-age children, where deficiency can lead to diminished motor, cognitive and behavioral functioning. Dietary Reference Values (DRVs) for iron are established using knowledge about iron status and bioavailability. **Aim**: This review evaluates evidence from published cross-sectional studies about whether dietary iron intake of primary school-age children is in symphony with DRVs. **Methods**: Two databases (PubMed and Scopus) were used to search for articles in November 2024. Studies were eligible if they included children aged 4-11 years and had a focus on DRVs and dietary iron intake. **Results**: 3,792 studies in total were screened and 20 studies, from multiple countries, were included. There was a lack of consistent terminology for reference intake values and large variation in recommended iron intake: 4.1 mg/day in UAE, 8.7 mg/day in UK, 26 mg/day in India, though most fell between 8 and 10 mg/day. Mean iron intake also varied from 6.3 mg/day to 27 mg/day. Iron intake as a percentage of recommended ranged from 36% to 339% (average 115%). Variations in iron intake could be attributed to heterogeneous dietary assessment methods, socioeconomic status, ethnicity and the use of fortified foods. **Conclusion**: Whilst many children worldwide have adequate iron intake, an appreciable fraction do not and are at risk of iron deficiency (ID), so children's health programs should focus on iron malnutrition which is of global public health concern.

1. Introduction

Iron (Fe), the most abundant transition metal in the human body (Salge Blake et al., 2013), is vital for optimal physiology, metabolism and overall health. This micronutrient's functions in the body are well documented in literature. Iron has an essential role in many biochemical reactions including DNA metabolism, oxygen transport and energy metabolism (Abbaspour et al., 2014; Fairweather-Tait, 2004). About two thirds of the body's iron is found as a component of haemoglobin (Hb) in erythrocytes (Abbaspour et al., 2014), providing a binding site for oxygen in the haem moiety of Hb to enable oxygen transport from the lungs to body tissues. Some iron is a component of myoglobin, a muscle protein to aid storage and release of oxygen in muscle tissue (Fairweather-Tait, 2004). Iron is also involved as an enzyme cofactor including cofactors involved in DNA synthesis and repair, for example helicases and nucleases. Iron plays a role in the synthesis of neurotransmitters, proteins and hormones and in neurological development (SACN, 2011). With the human body unable to synthesise iron, it must be obtained from dietary food sources and supplements.

There are two types of dietary iron: haem and non-haem iron. Haem iron is obtained from haemoglobin and myoglobin in animal source foods like meat, seafood, and poultry (Hurrell and Egli, 2010; SACN, 2011) and is absorbed with better efficiency. Non-haem iron (iron not attached to haem) is obtained from dark leafy greens, legumes, grains, fortified cereals and bread. It comprises over 90-95% of the iron consumed by omnivores and 100% for vegetarians and vegans (Johnston et al., 2007; Salge Blake et al., 2013). Iron can be added to foods during manufacture (fortification) and can also be taken as a supplement. Once ingested, iron absorption takes place mainly in the duodenum and upper jejunum. Insoluble ferric iron in the intestinal lumen is first reduced to absorbable ferrous iron, then transported into intestinal cells by a divalent metal transporter (DMT1), a protein on the apical membrane of enterocytes (Ems et al., 2023). Once iron has been

released via the transporter ferroportin into plasma, the circulating transporter, known as transferrin, binds to the iron and transports it to cells or bone marrow where it is used for cellular processes or stored in ferritin molecules (Abbaspour et al., 2014).

Iron bioavailability is the percentage of dietary iron that is absorbed and transferred by the intestinal mucosa and systemically utilised. This is dependent on dietary factors which can enhance or inhibit absorption, in particular non-haem iron which has a lower absorption rate (Finch et al., 1970; SACN, 2011). The evidence for a range of dietary factors influencing iron absorption comes from emerging in vitro and in vivo studies, and a growing body of literature outlines these factors. Phytate (from plant-based diets), and polyphenols (from plant foods and beverages like tea, coffee and wine) are major iron absorption inhibitors because they form insoluble complexes with dietary iron in the gastrointestinal tract (Schönfeldt et al., 2016). In addition, it is widely recognised that calcium and some egg proteins act as inhibitors, whilst ascorbic acid and meat digestion products act as enhancers (Piskin et al., 2022). However, literature shows less consensus as to the correlation between intake of dietary fibres and iron absorption, with studies reporting contradicting results (Feltrin et al., 2009). Other literature describes host factors which may influence iron bioavailability, including iron status, nutritional deficiencies, infection or inflammation and genetic disorders (Hurrell and Egli, 2010; Hallberg and Hulthén, 2000).

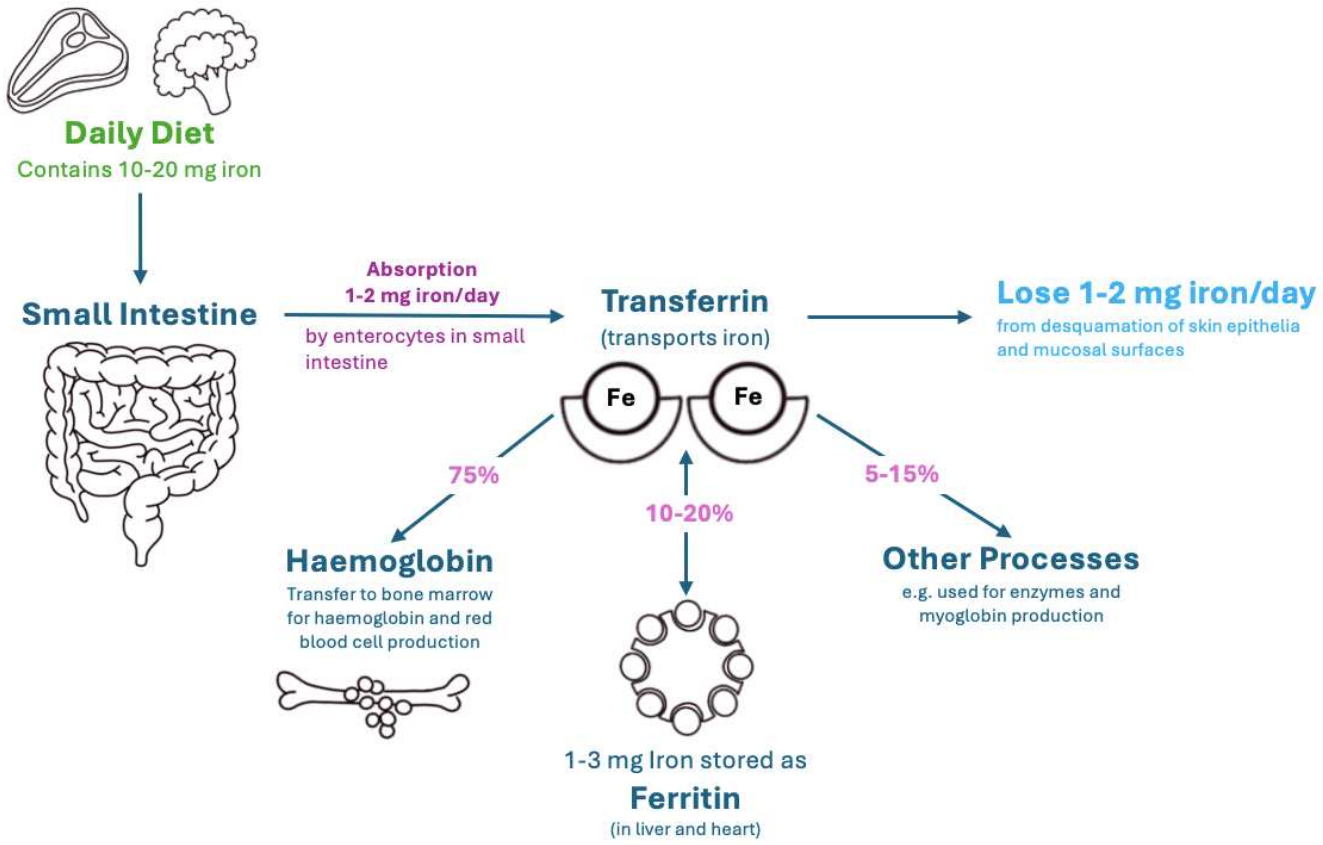

Figure 1. Schematic diagram of iron homeostasis in the body (Source: Author's own)

Since there is no physiological mechanism for the excretion of iron in the body, iron homeostasis (shown in Fig. 1), which maintains the fine balance between dietary uptake and loss, is mainly regulated by intestinal absorption (Hurrell and Egli, 2010). The amount of iron in the body, iron status, is controlled by balancing iron uptake with requirements for growth and adventitious losses, for example in blood loss, urine, sweat, and skin or hair loss (SACN, 2011). Whilst the average diet for an adult may contain 10-20 mg/day of iron, only 1-2 mg of this will be absorbed and only about 1-3 g of iron is ever stored in the body (Abbaspour et al., 2014). Approximately 1 mg of iron is lost each day via the sloughing of cells from skin and mucosal surfaces, and about 2 mg is lost per day in menstruating women. It is widely recognised that iron requirements vary greatly with age and sex; requirements surge during neonatal and childhood growth spurts, rising from 0.7 mg/day in 2-5 year-olds to 1.17 mg/day in 6-11 years-olds, and then, in females, rising again to 2.02 mg/day in 12-16 year-old females and to 2.38 mg/day in menstruating women (Abbaspour et al., 2014).

Iron status can be measured using biochemical indices. In population studies, the most widely used markers are the concentrations of blood serum ferritin (SF), Hb, and transferrin saturation, measured using blood analysis, which are then compared to reference values of healthy individuals (SACN, 2011). However, individuals do not routinely rely on blood analysis, but more often may compare their own daily dietary intake to reference intake values.

DRVs for iron have been established using knowledge about iron status, iron bioavailability and the factors that affect it. DRVs are quantitative estimates of the nutritional requirements for essential macro- and micro-nutrients for different population subgroups (COMA, 1991). Their purpose is to prevent nutritional deficiencies, and, for iron, are based on an estimation of the amount of dietary iron that must be consumed to meet the body's physiological needs. DRVs are reviewed and updated over time, in response to expanding knowledge about nutrient deficiencies and how nutrients can play a key role in preventing disease. A growing number of authors are also now recognising an increasing need to ensure excess consumption of micronutrients (from the growing usage of supplements and fortified foods) is avoided (Bateman et al., 2018). Iron toxicity, known to occur in children (Salge Blake et al., 2013), may occur if people overdose on iron supplements, or take high-dose supplements for too long, and this may lead to an increased risk of cancer. Therefore, as research evolves, DRVs are changed and updated.

DRVs also vary by country due to factors such as differences in dietary patterns, climate, and prevalent health conditions in different areas. In the UK, DRVs for iron comprise of Reference Nutrient Intakes (RNIs), the amount of iron required to meet the needs of 97.5% of the population, and Lower Reference Nutrient Intakes (LRNIs), the amount of iron sufficient for 2.5% of the population who have low requirements (COMA, 1991). The RNI for iron ranges from 1.7-14.8 mg/day (SACN, 2011). DRVs account for the bioavailability of iron, however the SACN Iron and Health Report (2011) notes that the bioavailability used to calculate DRVs may be overestimated, and therefore current DRVs may be too high - especially for females of reproductive age (SACN, 2011).

Epidemiological studies designed to assess whether individuals have adequate iron in their diet frequently make use of food intake surveys to calculate nutritional intake and then compare this with DRVs. Such

surveys may include Food Frequency Questionnaires (FFQ), a dietary assessment tool used to evaluate food intake of a population (Bhagyashri et al., 2024). Alternatively dietary recall surveys capture more detailed information (including portion size and meal timings) with more open-ended questions. If DRVs for iron are not met, nutritional ID may result. ID, the result of long-term negative iron balance when the supply of iron is insufficient to cover the body's requirements (Fairweather-Tait, 2004), affects a significant proportion of the population in almost every country (World Health Organization, 2001).

Owing to their higher physiological requirements and increased energy expenditure, children may be more vulnerable than adults to nutrient inadequacies including ID, especially during pre-adolescence when they begin to become more socially independent which Norton et al. (2003) suggest may have a negative impact on dietary intakes. In the UK, as well as in other developed countries, ID is known to be common during childhood and early adolescence (Friebe, 1996). Indeed, ID is the most common nutrient deficiency in young children in the USA (Salge Blake et al., 2013) and in developing countries, ID anaemia is estimated to affect half of school-age children (Stoltzfus et al., 1997). There is general agreement amongst researchers that ID can lead to diminished motor, cognitive and behavioural functioning and reduce learning capacity (Lozoff et al., 2000; Nelson, 1996). For example, ID may have a negative impact on attention span (Youdim et al., 1989), physical activity (Nelson et al., 1994), and on cognitive function, thus affecting academic achievement (Nelson, 1996), and on immunity mechanisms (Abbaspour et al., 2014). Millichap and Yee (2012) reviewed studies investigating ID and ADHD in children and reported that the most inattentive and hyperactive children had the most severe ID.

Other literature reports on more general statistics about the health of primary school-age children, such as a 2024 survey reporting that, in England, 1 in 8 children aged 2-10 years are obese. Results from the National Child Measurement Programme indicate that the prevalence of obesity doubles between reception and year 6 (around 10% to around 20%) (NHS, 2024; Office for Health Improvement & Disparities, 2024). Studies by Cepeda-Lopez et al. (2015) and Zimmermann et al. (2008) found increased adiposity is linked to decreased iron absorption and ID, reporting that iron absorption of obese women and children is two-thirds that of normal-weight subjects. These statistics indicate the diet of many children is inadequate. LaRowe et al. (2007) define a high-quality diet as one high in vitamins, minerals and trace elements. A high-quality diet is important during pre-adolescence to support physiological changes such as changes in fat and muscle proportions and motor skill development (Green and Palfrey, 2002), to prevent development of diet-related health issues later in life (Mikkilä et al., 2005) and to consolidate healthy eating habits which Norton et al. (2003) suggest are consolidated before the age of 10.

Clearly, adequate iron intake for primary school-age children (for the purpose of this study, defined as children aged 4 to 11 years) is fundamentally important. ID is associated with adverse health outcomes, including impaired cognitive development, poor immune function and slow growth as well as potential progression to anaemia. ID prevention is therefore of global public health concern. Considering the accumulative evidence regarding the negative effects of ID on health, understanding the extent to which children's iron intake aligns with DRVs could allow for a more comprehensive prevention approach in terms of health policy and potential strategies to address optimal intake. Assessment of dietary iron intake of

children worldwide is necessary to determine whether they are meeting dietary recommendations, and to guide public health strategies. Previous systematic reviews on this topic have often focused on infants, teenagers or pregnant women but few specifically examine iron intake in primary school-age children.

This systematic review aims to comprehensively review evidence from published cross-sectional studies, from both the UK and other countries, on iron intake in primary school-age children and to evaluate to what extent this aligns with DRVs.

2. Materials and Methods

2.1 Information sources and search strategy

Two databases, PubMed and Scopus, were used to search for articles in November 2024. The search strategy included terms on the following themes: dietary guidelines, nutrient recommendations, iron, health status, and primary school-age children. The full search strategy is shown in Table 1. There was no language restriction applied. Studies eligible for this review were observational and cross-sectional studies and filters for these article types were applied in PubMed. References of previous systematic reviews and all identified studies were reviewed. The International Clinical Trials Registry Platform was searched for potentially eligible ongoing clinical trials (World Health Organization, 2024). Studies published later than the time of the search were not included.

Table 1. Key Words and Search Terms used in the Systematic Review of the Literature

Dietary Guidelines		Iron / Related Terms		Age Group		Health Status
dietary guidelines [MeSH Terms]		Iron [MeSH Terms]		Primary age children		Diet*
OR recommended dietary allowance		**OR** iron*		**OR** School-age children		**OR** Intake*
OR dietary reference value		**OR** "anaemia"[MeSH Terms]		**OR** Children aged 4-11 years		**OR** Supplement*
OR nutrient recommendations		**OR** "anaemia"		**OR** Child*		**OR** Status
OR population reference intake	**AND**	**OR** "haemoglobin"[MeSH Terms]	**AND**		**AND**	**OR** Deplet*
OR dietary reference intakes		**OR** "haemoglobin"				**OR** Deficien*
OR nutrient reference values		**OR** "ferritin"				**OR** Concentration*
OR recommended dietary intake		**OR** "Iron deficiency"				**OR** Level*
OR estimated average requirement		**OR** "Iron nutrition"				
OR RDA **OR** DRV **OR** PRI **OR** DRI **OR** NRV **OR** RDI **OR** RNI **OR** NNR		**OR** "supplement"				

2.2 Inclusion and exclusion criteria

Studies were included if the study population included primary school-age children (age ranging 4-11 years). Studies which did not focus solely on primary school-age children, but included this age category, were included. Trials involving participants from all countries and socioeconomic backgrounds were included, and there was also no restriction on the duration of study and setting, but articles published before January 1990 were excluded to retrieve most up-to-date data. Studies which focused on iron supplementation were

excluded. Studies which examined dietary nutrient intake for a range of nutrients were included, if iron was one of those nutrients. Studies that specifically focused on DRVs or comparable guidelines were included. Studies not in English, without English translation or without full-text availability were excluded, as well as non-peer-reviewed and opinion pieces, to ensure the articles could be accurately analysed. Studies focused on specific medical conditions, including ID anaemia, were excluded as the research focus was on dietary intake and comparison to DRVs. Studies of children with different dietary habits were included.

2.3 Outcomes

To assess whether actual iron intake meets the reference iron intake, the following outcomes were used: Reference iron intake at time of study - either Recommended Daily Allowance (RDA), Dietary Reference Intake (DRI), Estimated Average Requirement (EAR), Nordic Nutrient Recommendation (NNR), Reference Nutrient Intake (RNI), Reference Daily Intake (RDI) and mean daily iron intake of subjects. In addition, iron intake as a percentage of reference was recorded (or calculated) and percentage of participants with adequate iron intake was recorded (if given).

2.4 Study selection

The titles and abstracts identified by the electronic database search were downloaded to the reference manager (EndNote), where duplicates were removed. These were screened based on title and abstract against the previously mentioned criteria. The full text of the remaining studies that was available was screened against the inclusion criteria. Studies identified via citation searching and manual searching were screened in the same way. Where available, full-text papers were retrieved for all potentially relevant studies based on the title and abstract. The remaining studies included were checked by a second reviewer.

2.5 Data Extraction

Data extraction included the year, study design, population description, study location, sample size, and dietary assessment methods. Details of the daily iron intakes, and DRVs used for each study were extracted.

2.6 Assessment of Risk of Bias (RoB)

The quality of each individual study being reviewed was appraised using the NIH quality assessment tool for Observational Cohort and Cross-Sectional Studies (National Institute of Health, 2021). This tool focused on concepts that are key for critical appraisal of the internal validity of a study. The aim was to evaluate potential flaws in study methods or implementation, including sources of bias e.g. subject selection and attrition, confounding, detection bias, attrition bias and study power. Answers to each appraisal domain could be “yes”, “no”, “cannot determine” (CD), “not reported” (NR) and “not applicable” (NA). For any item where “no” was selected, the potential risk of bias that could be introduced by that flaw in study design or implementation was considered. CD and NR were also noted as representing potential flaws.

3. Results

The selection of studies included is illustrated in Fig. 2. The search strategy identified 1,702 potentially eligible titles and abstracts. No potentially eligible unpublished trials were identified in the International Clinical Trials Registry Platform. Following screening, 20 studies were deemed eligible, and included in the systematic review.

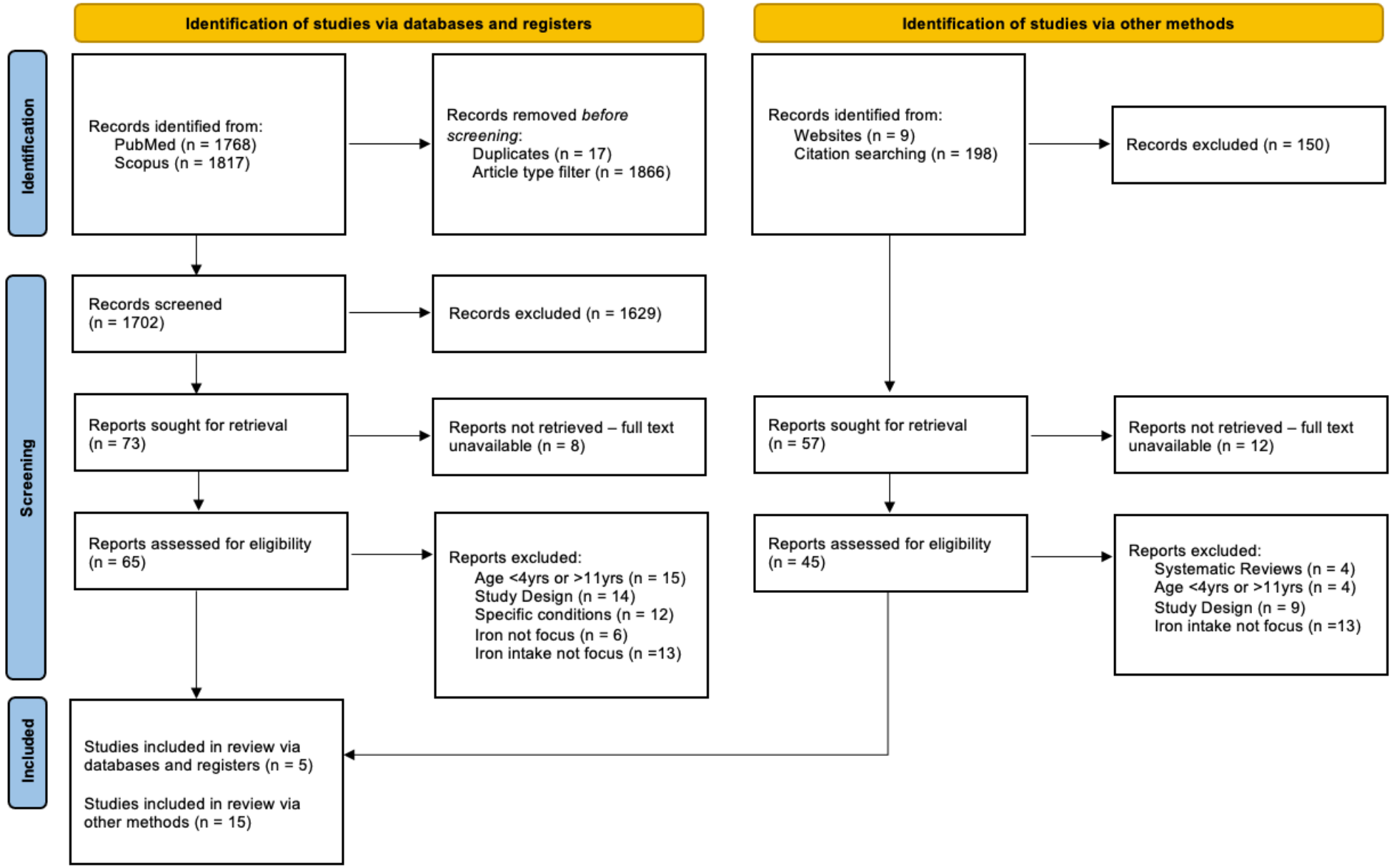

Figure 2. PRISMA study flow diagram for the study selection for the systematic review.

3.1 Study Characteristics

Table 1 presents the characteristics of the included studies. The 20 studies were conducted across multiple countries including 10 in Europe, 5 in Africa, 4 in Asia and 1 in North America, but all reports were in English language. The most frequent study location was the UK (6 studies). Using the World Bank income-based country classification (World Bank, 2023), 60% of studies were conducted in high-income countries (USA, all European countries and UAE), 10% of studies were conducted in upper middle-income countries (Thailand) and 30% of studies were conducted in lower middle-income countries (African countries and India). The 20 studies included a total of 21,522 children and young people (with 72% of these falling within the primary school-age range). The age of survey participants ranged from 0.5-24 years, but only data for primary school-age children was analysed in this review. The most common age of study participants was 7 (included in 17 studies), followed by 8, 9 and 10 years (included in 16 studies). Younger primary school-age children aged 4 and 5 years were included in 5 and 8 studies respectively. Only one study (Glynn et al., 2005) looked at children who were all the same age (7 years old). The publication years ranged from 1992 (Adamson et al.) to 2023 (Rana and Khetarpaul). There was a wide variation of sample sizes, the smallest being 85 (Jennings et al., 2009) and the largest being 3,534 (Serra-Majem et al., 2006). The dietary intake survey methods varied between 24-hour diet recalls (24HR), Food Records (FR) and FFQs. Only 4 out of the 20 studies used weighted data when recording dietary intake. 15 studies reported the reference iron intake, and 16 studies reported the mean daily iron intake of participants. All studies recruited both males and females but only 12 studies gave a breakdown of results by sex. One study compared omnivores and vegetarians, and one study compared urban and rural children.

Table 2. Study characteristics of the included studies

Study author(s)	Country	Date Published	Age at recruitment (years)	Sample Size * (by age in years)		Dietary Assessment Methods **	Weighted Food Intake Data
Adamson et al.	United Kingdom	1992	11 - 12		N = 379	2x 3-day FR	No
Akeredolu et al.	Nigeria	2011	5 - 13		N = 200	24HRs	No
Ali et al.	United Arab Emirates	2013	6 - 18		N = 529	24HRs	No
				(6 - 8)	N = 163		
				(9 - 13)	N = 195		
Andersen et al.	Denmark	2015	8 - 11		N = 798	7-day FR	No
Ayogu et al.	Nigeria	2015	6 - 15		N = 450	3-day FR	Yes
				(6 - 9)	N = 32		
				(10 - 12)	N = 25		
Donin et al.	United Kingdom	2010	9 - 10		N = 2209	24HRs	No
Glynn et al.	United Kingdom	2005	7		N = 663	3-day FR	No
Hassan et al.	Nigeria	2012	7 - 11		N = 394	24HRs	No information
Jennings et al.	United Kingdom	2009	7 - 10		N = 85	7-day FR	Yes
Kyttälä et al.	Finland	2010	1 - 6		N = 2535	3-day FR	No
				(4)	N = 554		
				(6)	N = 713		
Nathan et al.	United Kingdom	1996	7 - 11		N = 100	3-day FR	No
Rana and Khetarpaul	India	2023	5 - 10		N = 200	24HRs	No information
Rojroongwasinkul et al.	Thailand	2013	0.5 - 12.9		N = 3119	24HRs	No
				(3 - 5.9)	N = 860		
				(6 - 12.9)	N = 1570		
Serra-Majem et al.	Spain	2006	2 - 24		N = 3534	2x 24HRs	No
				(6 - 9)	N = 398		
				(10 - 13)	N = 514		

Study author(s)	Country	Date Published	Age at recruitment (years)	Sample Size * (by age in years)		Dietary Assessment Methods **	Weighted Data
Shell-Duncan and McDade	Kenya	2005	5 - 10		N = 300	24HRs	No
Suitor and Gleason	United States	2002	6 - 18		N = 2692	2x 24HRs	No information
				(6 - 8)	N = 693		
				(9 - 13)	N = 1112		
Suteerojntrakool et al.	Thailand	2021	6 - 12.9		N = 336	24HRs	No
Tatala et al.	Tanzania	2004	7 - 12		N = 101	FFQ	No
Thane et al.	United Kingdom	2003	4 - 18		N = 1520	7-day FR	Yes
				(4 - 6)	N = 318		
				(7 - 10)	N = 435		
				(11 - 14)	N = 421		
Zaragoza-Jordana et al.	Germany, Belgium, Italy, Poland, Spain	2018	0 - 8		N = 1678	3-day FR	Yes
				(4)	N =503		
				(5)	N = 445		
				(6)	N = 468		
				(7)	N = 396		

*Entire study sample size given, with sample size for children in primary school-age range of interest given in parenthesis
**FFQ = Food frequency questionnaire, 24HRs = 24-hour diet recalls, FRs = food records

3.2 Risk of Bias Assessment

Fig. 3 (A) presents the summary of the RoB assessment of the included articles, by domain. There was no RoB in all studies for D1, D2, D4, D9 and D14, which cover the research question definition, study population definition, subject selection/recruitment, exposure measures and assessment and confounders. Therefore, the quality of these study characteristics was considered high. All but one study scored 'Yes' for D11, indicating that outcome measures were usually clearly defined and consistently implemented. All but 3 studies carried out statistical analysis to adjust for confounders (D15). The domain for which there was least information given was D3, so it was not always clear if participation rate of eligible persons was 50%. D6 and D7 were NA since exposure (age) and outcome (iron intake) were measured simultaneously. D10 (assessing exposure over time) was NA for all studies; age measurements did not need to be repeated. The question 'Were the outcome assessors blinded to the exposure status of participants?' (D12) was considered NA for all studies due to the age of participants being an objective characteristic, a factor that cannot be blinded in the study design. There was no follow up in all studies included, therefore D13 was NA. The domain with the least 'Yes' results, shown in Fig. 3 (B) was D5, with only 4 studies justifying sample size. 2 studies scored 'Yes' or NA results in all domains suggesting very high-quality studies with no RoB. No studies had more than 2 'No' results, suggesting overall that the studies had few flaws, high validity and low RoB.

A)

Study	Domains to check study quality														
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15
Adamson et al. (1992)	+	+	+	+	X			X	+		+			+	+
Akeredolu et al. (2011)	+	+	?	+	+			+	+		+			+	+
Ali et al. (2013)	+	+	+	+	X			+	+		+			+	+
Andersen et al. (2015)	+	+	+	+	X			+	+		+			+	+
Ayogu et al. (2015)	+	+	X	+	+			+	+		+			+	+
Donin et al. (2010)	+	+	+	+	X			X	+		+			+	+
Glynn et al. (2005)	+	+	+	+	X			X	+		+			+	+
Hassan et al. (2012)	+	+	?	+	X			X	+		+			+	?
Jennings et al. (2009)	+	+	+	+	X			X	+		+			+	+
Kyttälä et al. (2010)	+	+	?	+	X			+	+		+			+	?
Nathan et al. (1996)	+	+	+	+	X			X	+		+			+	+
Rana and Khetarpaul (2020)	+	+	?	+	X			X	+		+			+	+
Rojroongwasinkul et al. (2013)	+	+	+	+	+			+	+		+			+	+
Serra-Majem et al. (2006)	+	+	+	+	X			+	+		+			+	+
Shell-Duncan and McDade (2005)	+	+	?	+	X			X	+		+			+	+
Suitor and Gleason (2002)	+	+	?	+	X			+	+		?			+	+
Suteerojntrakool et al. (2021)	+	+	+	+	+			+	+		+			+	+
Tatala et al. (2004)	+	+	?	+	X			?	+		+			+	+
Thane et al. (2003)	+	+	+	+	X			+	+		+			+	+
Zaragoza-Jordana et al. (2018)	+	+	+	+	X			+	+		+			+	?

D1: Was the research question or objective in this paper clearly stated?
D2: Was the study population clearly specified and defined?
D3: Was the participation rate of eligible persons at least 50%?
D4: Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?
D5: Was a sample size justification, power description, or variance and effect estimates provided?
D6: For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?
D7: Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?
D8: For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome?
D9: Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?
D10: Was the exposure(s) assessed more than once over time?
D11: Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?
D12: Were the outcome assessors blinded to the exposure status of participants?
D13: Was loss to follow-up after baseline 20% or less?
D14: Were key potential confounding variables measured?
D15: Were key potential confounding variable adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?

Judgement
X No (= High ROB)
+ Yes (= Low ROB)
? No information
Not applicable

B)

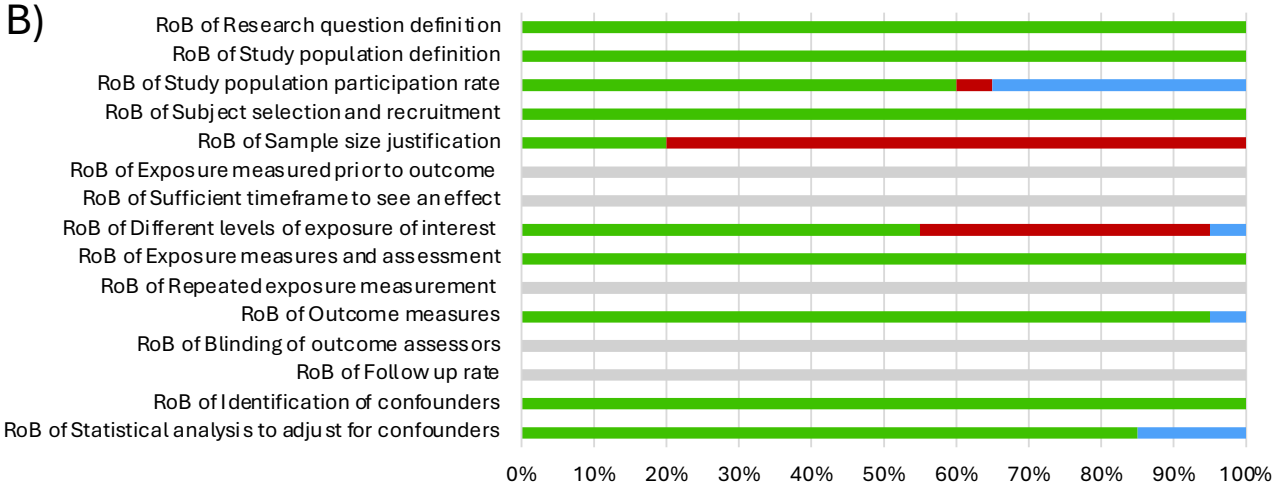

Figure 3. (A) Robvis traffic light plots of the RoB assessment of the studies according to the NIH quality assessment tool (National Institute of Health, 2021). (B) Summary of the RoB per domain (Adapted from: McGuinness and Higgins, 2020).

3.3 Iron DRV and mean iron intake

Table 3 summarises the key findings of each study: the DRV, mean iron intake of participants, iron intake as a percentage of DRV and percentage of study participants who had adequate iron intake.

3.3.1 DRVs

There was a lack of consistency in terminology used in the studies for reference intake values. 7 studies referred to RNI, 2 studies referred to RDA, 1 study referred to DRI, 1 study referred to EAR, 2 studies referred to NNR (the Scandinavian studies), and 2 studies referred to RDI. Some studies (Glynn et al., 2005; Jennings et al., 2009, Nathan et al., 1996, Thane et al., 2004) also referred to the LRNI (lower reference nutrient intake). The iron DRVs for primary school-age children varied greatly between studies since the studies gave reference intakes for differing age categories, so it was not always easy to make direct comparisons.

15 studies referred to reference intake values for iron. These values ranged from 4.1 mg/day for 6-8 year-olds in the UAE (Ali et al., 2013), to 26 mg/day for 5-10 year-olds in India (Rana and Kheterpaul, 2020), as seen in Fig. 4, illustrating major differences between countries. However, there was sometimes more consistency between studies in the same country: 4 of the UK studies that looked at the iron intake of children within the age range 7-11 years all quoted DRVs of 8.7 mg/day. Both Scandinavian studies quoted a reference intake of 9 mg/day for 6 year-olds. However, there was less consistency between the DRVs reported by the African studies with 2 of the Nigerian studies reporting widely different values: the study by Akeredolu et al. (2011) quoted the DRI for 5-8 year-olds to be 10 mg/day whilst the study by Ayogu et al. (2015) quoted a much higher RNI for 6-9 year-olds of 16 mg/day. Neighbouring African countries Kenya and Tanzania also reported very different DRVs, with Shell-Duncan and McDade (2005) giving an RDA of 10 mg/day for 5 -10 year-old Kenyan children, whereas Tatala et al. (2004) gave a RDI of 23 mg/day for 7-12 year-old Tanzanian children. However, the latter was described as a reference intake for a diet with very low iron bioavailability, something not mentioned in other studies. The European countries that gave reference iron intakes for primary school-age children gave values between 6.1 mg/day (for 4-6 year-olds in the UK) (Thane et al., 2003) to 15 mg/day (for 10-13 year-olds in Spain) (Serra-Majem et al., 2006).

5 studies did not refer to reference iron intakes. These included both the Thailand studies, the American study and the study by Zaragoza-Jordana et al. (2018) which studied children from 5 different European countries. Some of these referred to national reference intakes without quoting specific numerical values; for example, the study by Suteerojntrakool et al. (2021) referred to 'Thai dietary recommended intake 2003' but did not quote values and these could not be established from references. 9 of the studies reported reference intakes for both male and female children as separate values. In 8 of these studies, these values for males and females were the same, though in the study by Ali et al. (2013) reference iron intake (EAR) was given as 5.9 mg/day for UAE 9-13 year-old males and 5.7 mg/day for UAE 9-13 year-old females.

3.3.2 Iron intake

The food composition tables that were used to calculate iron intake from the diet were based, in most studies, on national nutrient databases. The Scandinavian studies used the Nordic Nutrition Recommendations (NNR), and the UK studies used the Government Dietary Reference Values (DRVs) from 1991 (though the older

UK study by Adamson et al. (1992) used Recommended Dietary Allowance from 1979). 15 studies reported mean iron intake (in mg/day) and 1 study reported median iron intake. 4 studies did not report iron intake.

The iron intakes varied widely from 6.0 mg/day in 3-5.9 year-olds and 6.3 mg/day in 6-12.9 year-olds in Thailand (Rojroongwasinkul et al., 2013) to 27 mg/day in 7-12 year-old males in Tanzania (Tatala et al., 2004). It should, however, be noted that the study by Rojroongwasinkul et al., (2013) that recorded such a high mean iron intake used FFQs as a method of assessing dietary intake, unlike the other studies which used 24HR or FR. Of the studies that used 24HRs or FRs, the highest recorded iron intake was 18.8 mg/day in 10-12 year-old males in Tanzania (Ayogu et al., 2015). Within the UK, reported dietary iron intake varied less, from 7.4 mg/day in 7 year-old females (Glynn et al., 2005) to 11.7 mg/day in 11-12 year-old males (Adamson et al., 1992). There were some similarities seen between different studies within the same country using children of similar age groups; for example in the UK, Donin et al. (2010) reported iron intake to be 8.6 mg/day in 9-10 year-old females and 9.1 mg/day in 9-10 year-old males, whilst Jennings et al. (2009) reported iron intake to be 8.2 mg/day in 7-10 year-old females and 9.5 mg/day in 7-10 year-old males. However, in the 2 Nigerian studies this was not the case with Hassan et al. (2012) reporting iron intake for 7-9 year-olds as 10.1 mg/day but Ayogu et al. (2015) reporting a much higher iron intake for 6-9 year-olds of 15.8 mg/day.

Where studies reported iron intake for both males and females (10 studies), iron intake was higher for males on all but one occasion, though this difference was often small (0.5-3.0 mg/day difference). Nathan et al. (1996) reported UK vegetarian 7-11 year-olds to have slightly higher iron intake than omnivores of the same age and Rojroongwasinkul et al. (2013) reported Thai urban children to have slightly higher iron intake than rural children of the same age.

3.3.3 Iron intake compared to DRV

Iron intake as a percentage of DRV was given in 15 studies and Fig. 4 shows the difference between mean iron intake and DRV in studies where both values were given. The values reported ranged from 36% for 5-10 year-old females in India (Rana and Khetarpaul, 2020) to 339% for 6-8 year-old females in the UAE (Ali et al., 2013). 6 studies reported that all primary school-age groups had a mean iron intake below that recommended, 3 studies reported that all age groups had a mean iron intake above recommended, and 5 studies reported that some age groups had a mean iron intake below DRV, but some age groups had a mean iron intake above DRV. When median iron intake was reported in one study (Akeredolu et al., 2011), it was above the reference intake; this indicated that more than 50% of children had an iron intake above the recommended.

Of the 6 UK studies, only one study reported all subjects to have an iron intake above reference value (Nathan et al., 1996), but all other UK studies reported that children in some age groups or of one sex had an iron intake below reference. For example, Thane et al. (2003) reported that whilst all 4-6 year-olds had an iron intake above reference, only male 7-10 year-olds did and no 11-14 year-olds did. Jennings et al. (2009) reported 7-10 year-old males to have iron intake above reference but females of the same age were below reference. Iron intake as a percentage of reference value decreased with age in the studies by Thane et al. (2003), Serra-Majem et al. (2006), Kyttala et al. (2010) and Ali et al. (2013), but this was not the case in some other studies. Where a breakdown was given by sex, 9 studies reported that females always had a lower percentage than

males for intake compared to reference, the exception being the study by Ali et al. (2013) which reported males having a lower percentage of reference intake than females. Two studies gave much higher reference values for iron intake than the other studies; in these 2 studies, Rana and Khetarpaul (2020) reported that 5-10 year-old Indian children only had just over a third of this high reference intake, but Tatala et al. (2004) reported that 7-12 year-old Tanzanian children had just over 100% of this high reference intake. 6-13 year-old children in the UAE were reported to have mean iron intakes which were more than double or triple the EAR, but such high values were not seen in any other studies where the maximum intake as a percentage of reference (*not* EAR) was 142%.

8 studies reported the percentage of study participants who had an iron intake which was adequate. Only one of these studies reported a value of 100% (for American females 9-13 years) (Suitor and Gleason, 2002). The 7 other studies reported values between 16% (Danish 10-13 year-olds) (Anderson et al., 2015) and 99% (American 6-8 year-olds) (Suitor and Gleason, 2002). 5 out of these 8 studies reported that 50% or less children had adequate iron intake. 4 studies (Adamson et al., 1992; Jennings et al., 2009; Nathan et al., 1996; Tatala et al., 2004) gave both mean iron intake as a percentage of reference value and the percentage of subjects with adequate iron intake. In all 4 cases, whilst mean iron intake was reported to be between 93% and 126% of recommended, there were only between 18 and 66% of subjects with adequate iron intake, indicating that even when *mean* iron intake appears adequate (or nearly adequate), there are still large percentages of children with inadequate iron intake.

Table 3: Reference Iron Intake and Actual Dietary Iron Intake for Primary School-age Children

Study	Country	Age (years)	Sample Size	Reference iron intake at time of study mg/d (year)		Mean Iron Intake (mg/day)	Iron intake as % of reference intake	% of participants with adequate iron intake
Adamson et al. (1992)	**United Kingdom**	11-12	N = 379	12.0	RDA (1979)			40-47%
		11-12 (M)	N = 184	12.0	RDA (1979)	11.7	98%	
		11-12 (F)	N = 195	12.0	RDA (1979)	11.2	93%	
Akeredolu et al. (2011)	**Nigeria**	5-13	N = 200					
		5-8		10.0	DRI (2001)	10.2 *	102%	
		9-13		8.0	DRI (2001)	10.7 *	134%	
Ali et al. (2013)	**United Arab Emirates**	6-18	N = 529					
		6-8 (M)	N = 78	4.1	EAR (2011)	12.6	307%	
		6-8 (F)	N = 85	4.1	EAR (2011)	13.9	339%	
		9-13 (M)	N = 102	5.9	EAR (2011)	14.1	239%	
		9-13 (F)	N = 93	5.7	EAR (2011)	13.7	240%	
Andersen et al. (2015)	**Denmark**	8-11	N = 798			8.6		
		8-11 (M)	417			9.3		
		8-11 (F)	381			7.9		
		6-9		9.0	NNR (2012)			40%
		10-13		11.0	NNR (2012)			16%
Ayogu et al. (2015)	**Nigeria**	6-15	N = 450					
		6-9	N = 32	16.0	RNI (2001)	15.8	99%	
		6-9 (M)		16.0	RNI (2001)	16.5	103%	
		6-9 (F)		16.0	RNI (2001)	15.2	95%	
		10-12	N = 25	16.0	RNI (2001)	17.8	111%	
		10-12 (M)		16.0	RNI (2001)	18.8	118%	
		10-12 (F)		16.0	RNI (2001)	16.8	105%	
Donin et al. (2010)	**United Kingdom**	9-10	N = 2209					
		9-10 (M)	N = 1065	8.7	RNI (1991)	9.1	105%	
		9-10 (F)	N = 1144	8.7	RNI (1991)	8.6	99%	
Glynn et al. (2005)	**United Kingdom**	7	N = 814	8.7	RNI (1991)	7.8	90%	
		7 (M)	N = 443	8.7	RNI (1991)	8.1	93%	
		7 (F)	N = 371	8.7	RNI (1991)	7.4	85%	
Hassan et al. (2012)	**Nigeria**	7-11	N = 394			11.0		48%
		7-9				10.1		
		10-11				11.6		

Study	Country	Age (years)	Sample Size	Reference iron intake at time of study mg/d (year)		Mean Iron Intake (mg/day)	Iron intake as % of reference intake	% of participants with adequate iron intake
Jennings et al. (2009)	**United Kingdom**	7-10	N = 85	8.7	RNI (1991)	8.6	99%	62%
		7-10 (M)	N = 21	8.7	RNI (1991)	9.5	109%	66%
		7-10 (F)	N = 64	8.7	RNI (1991)	8.2	94%	52%
Kyttälä et al. (2010)	**Finland**	1-6	N = 2535					
		4	N = 554	8.0	NNR (2005)	7.5	94%	
		6	N = 713	9.0	NNR (2005)	8.1	90%	
Nathan et al. (1996)	**United Kingdom**	7-11	N = 100					
		7-11 (O)	N = 50	8.7	RNI (1991)	10.6	122%	28%
		7-11 (V)	N = 50	8.7	RNI (1991)	11.2	126%	18%
Rana and Khetarpaul (2020)	**India**	5-10	N = 200					
		5-10 (M)	N = 117	26.0	RDI (2004)	9.5	37%	
		5-10 (F)	N = 83	26.0	RDI (2004)	9.4	36%	
Rojroongwasinkul et al. (2013)	**Thailand**	0.5-12.9	N = 3119					
		3-5.9 (U)	N = 62			6.6		
		3-5.9 (R)	N = 116			6.0		
		6-12.9 (U)	N = 101			6.6		
		6-12.9 (R)	N = 217			6.3		
Serra-Majem et al. (2006)	**Spain**	2-24	N = 3534					
		6-9 (M)	N = 203	9.0	RNI (1994)	12.8	142%	
		6-9 (F)	N = 195	9.0	RNI (1994)	11.3	126%	
		10-13 (M)	N = 261	15.0	RNI (1994)	15.1	101%	
		10-13 (F)	N = 253	15.0	RNI (1994)	12.7	85%	
Shell-Duncan and McDade (2005)	**Kenya**	5-10	N = 300	10.0	RDA (1989)			
		5-10 (Ko)		10.0	RDA (1989)	6.5	65%	
		5-10 (Ka)		10.0	RDA (1989)	9.3	93%	
Suitor and Gleason (2002)	**United States**	6-18	N = 2692					
		6-8	N = 693					99%
		9-13	N = 1112					100%

Study	Country	Age (years)	Sample Size	Reference iron intake at time of study mg/d (year)		Mean Iron Intake (mg/day)	Iron intake as % of reference intake	% of participants with adequate iron intake
Suteerojntrakool et al. (2021)	**Thailand**	6-12.9	N = 336				59%	
		6-8	N = 101					
		6-8 (M)	N = 53					
		6-8 (F)	N = 48					
		9-12	N = 235					
		9-12 (M)	N = 129					
		9-12 (F)	N = 106					
Tatala et al. (2004)	**Tanzania**	7-12	N = 101	23.0	RDI (2001) **	25.0	109%	50%
		7-12 (M)	N= 40	23.0	RDI (2001) **	27.0	117%	
		7-12 (F)	N = 61	23.0	RDI (2001) **	24.0	104%	
Thane et al. (2003)	**United Kingdom**	4-18	N = 1520					
		4-6		6.1	RNI (1991)			
		4-6 (M)	N = 167				131%	
		4-6 (F)	N = 151				118%	
		7-10		8.7	RNI (1991)			
		7-10 (M)	N = 228				109%	
		7-10 (F)	N = 207				96%	
		11-14						
		11-14 (M)	N = 212	11.3	RNI (1991)		94%	
		11-14 (F)	N = 209	14.8	RNI (1991)		59%	
Zaragoza-Jordana et al. (2018)	**Germany, Belgium, Italy, Poland, Spain**	0-8	N = 1678					
		4	N = 503					75%
		5	N = 445					81%
		6	N = 468					87%
		8	N = 396					43%

* Median Iron Intake (mg/day)
** RDI for a diet with very low bioavailability

Abbreviations:

(M/F) = (Male/ Female)
(U/R) = (Urban/ Rural)
(O/V) = ` (Omnivore/Vegetarian)
(Ko/Ka) = (Korr/ Karare)

RDA = Recommended Daily Allowance (United Kingdom, 1992; Kenya, 2005).
DRI = Dietary Reference Intake (Nigeria, 2011)
EAR = Estimated Average Requirement (United Arab Emirates, 2013)
NNR = Nordic Nutrient Recommendation (Finland, 2010; Denmark, 2015)
RNI = Reference Nutrient Intake (Nigeria 2015; United Kingdom, 1996, 2003, 2005, 2009, 2010; Spain, 2006)
RDI = Reference Daily Intake (India, 2020; Tanzania, 2004)

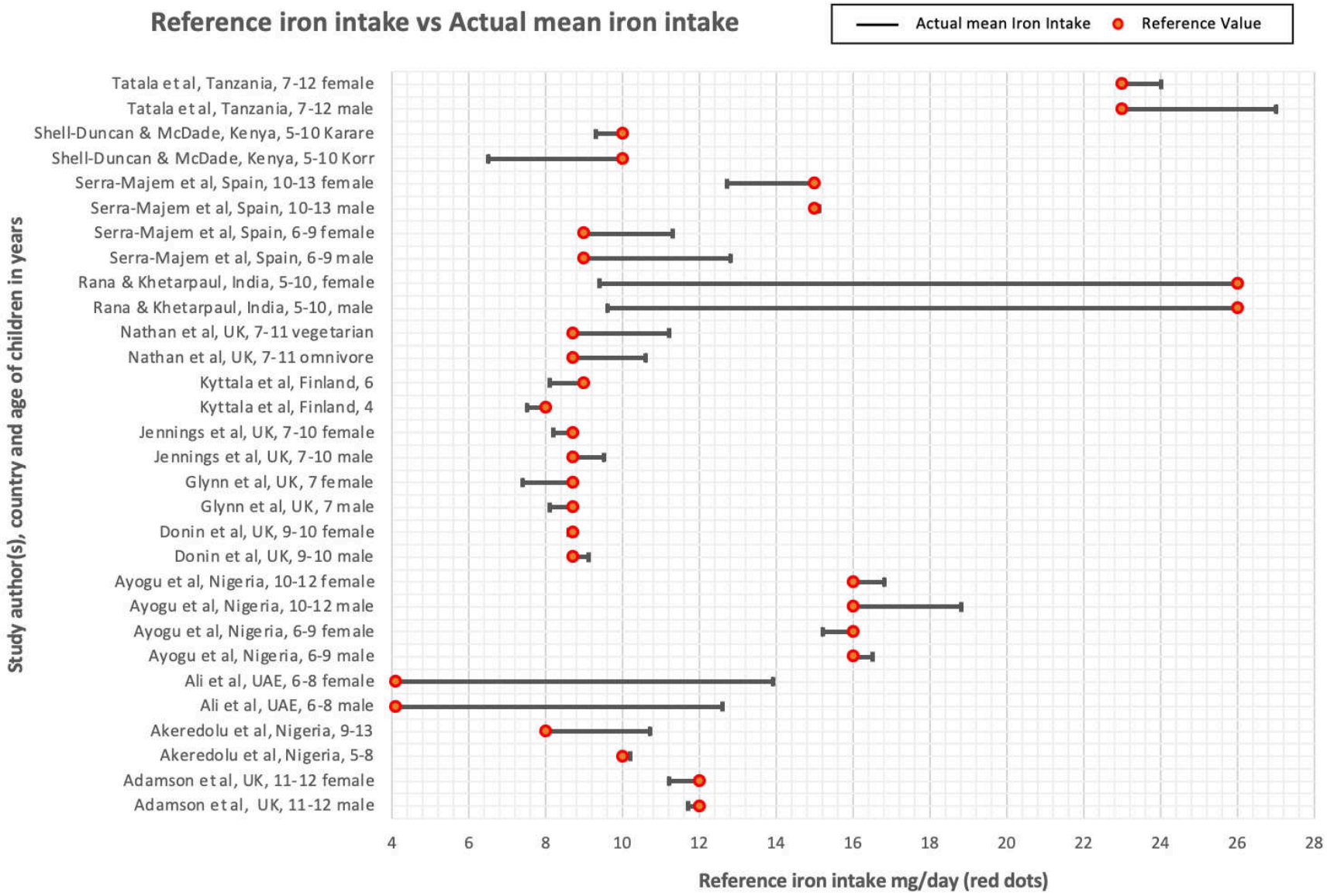

Figure 4. Comparison of actual mean iron intake with reference values. Black lines represent actual intake, while red dots indicate reference daily intake values (mg/day).

4. Discussion

4.1 Terminology used for DRVs

The 20 studies reviewed showed a lack of consistency in the terminology used for reference intake values, both internationally and nationally. For example, all but one of the UK studies referred to RNIs, the exception being the older study by Adamson et al. (1992) which referred to RDA. The UAE study was the only one to use EARs (the estimated requirement for 50% of the population group), so when interpreting data, it is important to appreciate that these terms refer to different values. *Dietary reference intake* (DRI) is an umbrella term used to describe a set of reference values for nutrient intakes and, whilst the terms DRV or RNI are used in most European countries, some adopt different terms. For example, Nordic and Baltic countries first published NNRs in 1980 and these national dietary reference values and food based dietary guidelines have been regularly updated since then (Christensen et al., 2020). NNRs were used in both Scandinavian studies in this review. None of the studies used the term Population Reference Intake proposed by EFSA (EFSA, 2010) which is the level of nutrient intake adequate for virtually all subjects in a population group. However, despite these differences in terminology, all studies referring to reference intake values applied the DRI framework in a similar manner.

4.2 Variation in DRVs

This review found significant disparities in the DRVs for primary school-age children globally. They ranged from 4.1 mg/day (EAR) for children in the UAE, to 8.7 mg/day for UK children, to 26 mg/day for children in India. The majority of DRVs, however, fell between 8 and 10 mg/day as seen in Fig. 4. These differences can be explained by the bases for calculation. Worldwide, the WHO is the most prevalent source of dietary recommendations, these being adopted by 97 countries (Freeland-Graves et al., 2020). However, some countries are known to have created their own national recommendations, such as the UK, DACH (Germany, Austria and Switzerland) and Thailand (Freeland-Graves et al., 2020). The scientific basis for the establishment of iron DRVs used by many organisations (including WHO, EFSA, DACH and Nordic countries) utilises a factorial approach, whereby the quantity of iron necessary to counterbalance obligatory losses (based on life stage and gender) as well as bioavailability factors to account for dietary absorption are computed (Freeland-Graves et al., 2020). Iron bioavailability is known to vary between diet types (14-18% for individuals from industrialised countries with a mixed diet and no iron stores, to 5 -12% for individuals with a vegetarian diet) and may also be lowered if individuals have a diet high in fortified foods (Hurrell and Egli, 2010). With numerous factors affecting iron bioavailability, traditionally industrialised countries have used mean iron bioavailability factor, irrespective of diet, to generate DRVs for iron for all population groups (Hurrell and Egli, 2010). Indeed, in most studies reviewed, assumed bioavailability was not stated, the exception being the Tanzanian study (Tatala et al., 2004) which did state that their RDIs were for a diet with very low bioavailability. Greater consensus in the use of DRVs may be established if the range of factors which affect iron bioavailability are considered, though it should be noted that most data on iron homeostasis to date have been established in adults, rather than children (Chouraqui, 2022). Freeland-Graves et al. (2020) reported that dietary requirements for iron were greater for adults in developing nations such as India and SE Asia, than for developed nations including

the USA, UK and Nordic countries. This difference was also evident for the iron DRVs in the studies reviewed, with Tanzania and India having the highest DRVs (23 and 26 mg/day respectively).

Another factor that could explain the large variation in DRVs is that micronutrient recommendations are known to have increased over the last 30 years (Freeland-Graves et al., 2020), especially in developed countries that place greater emphasis on disease prevention associated with longevity and sedentary lifestyles. In developing countries there is often less government investment in the health sector along with greater emphasis on simply addressing basic needs, so DRVs have remained largely unaltered, thus the recency by which DRVs have been updated can cause inconsistencies. There is some demand for new scientific nutrition and public health evidence to be used to regularly update micronutrient recommendations (Cavelaars et al., 2010). In addition, different organisations and countries use inconsistent age categories when setting out DRVs. For example, the WHO/FAO use 4-6 years, 7-10 years and 11-14 years as categories whilst the Institute of Medicine (IOM) use 4-8 years and 9-13 years (Chouraqui, 2022). This again made comparisons of DRVs between studies more challenging. Finally, it is known that iron requirements have an asymmetrical distribution (Carriquiry, 1999) which complicates the evaluation of DRVs for iron, and may be reflected in the large variation in reference values seen in this review.

4.3 Reliability of assessment of iron intake

All studies described the method used to assess dietary intake, but these varied which may impede direct comparisons between studies. 1 study used a FFQ, 10 studies used a 24HR (2 of which repeated this twice), 6 studies used a 3-day FR, and 3 studies used a 7-day FR. A report by The European Food Consumption Survey Method group states that using 24HR, conducted twice, is the most suitable method to gain internationally comparable data on population means and distributions of actual nutrient intake (Brussaard et al., 2002). Only 55% of the studies reviewed fulfilled these criteria so whether results can be reliably compared between studies is questionable. There is disagreement as to the relative validity of FFQs to assess dietary iron intake; Heath et al. (2000) suggest they are appropriate but Luftimas et al. (2021) suggest measurements using FFQs are lower than Food Diaries or Weighed FRs. Milman (2019) states that FFQs should not be used to assess iron intake since they report significantly higher iron intakes than food recalls. The latter view is consistent with findings of this review, where the study which used a FFQ reported the highest daily iron intake. Some authors suggest that iron intake reported from 24HRs is higher compared to intake using FRs (De Keyzer et al., 2011), though this was not obvious in this review. For example, of the 2 Nigerian studies, the one which used 24HR reported lower mean intakes. In addition, national food composition tables (which reflect the composition of the most common staple foods consumed in a country) would have varied between countries and therefore studies may have had different data when calculating iron intake.

4.4 Daily Iron Intake

Daily iron intake, reported by 16 of the 20 studies reviewed, varied between 6 and 27 mg/day (and within the UK between 7.4 and 11.7 mg/day), though different dietary assessment methods used could explain

some of this large variation. The studies covered a period of 29 years, but it seems that overall dietary iron intake has not varied with any distinguishable pattern during this time. This agrees with the findings of Ruxton and Derbyshire (2011) who studied dietary intakes of UK schoolchildren over time. Many of the studies gave a breakdown on iron intake by age group, and, as would be expected since they are likely to consume greater quantities of food, older children usually had a slightly higher iron intake. Males usually had a slightly higher iron intake than females in most studies that reported this breakdown, even though adolescent females are known to have higher iron requirements than their male counterparts. In adults, this gender difference could possibly be explained by the fact that men and women often choose slightly different diets with different nutrient densities which can impact iron intake (Milman, 2020), but such differences are less likely to exist in primary school-age children. Only one study reported differential intakes between vegetarian and omnivore children, with iron intake for vegetarians being 0.4 mg/day higher than for omnivores. Since non-haem iron (the only form consumed by vegetarians) is less bioavailable, the IOM states that vegetarians have an iron requirements 1.8 times higher than non-vegetarians (Trumbo et al., 2001), so the fact that they consumed more iron in the study by Nathan et al. (1996) is encouraging.

The variations seen in iron intake between the studies is likely to be due to a wide range of factors, including nutrient density for iron. Dietary habits affecting iron nutrient density differ by country, especially regarding the intake of meat, fish and poultry (containing easily absorbed haem iron) and other foods which contain less easily absorbed non-haem iron. Whilst some of the studies reviewed reported the major foods consumed by subjects, the contribution of these foods to iron intake was not always analysed, especially since this review was based on published studies so there was no access to raw data, so it was difficult to be specific about how different dietary habits cause differential iron intakes. However, Nathan et al. (1996) stated that breakfast cereals were the main source of iron for both vegetarian and omnivore children and Ayogu et al. (2015) went as far as to suggest the main reasons for inadequate iron intake in some Nigerian subjects was due to skipping breakfast and being unable to eat animal sources of iron due to their high cost. Rana and Khetarpaul (2020) attributed the very low iron intake in Indian children to low consumption of green leafy vegetables and fruits by most children.

Another factor that may explain the varied iron intakes is fortification of foods; iron fortification will contribute a larger iron nutrient density and thus lead to a higher dietary iron intake. Iron fortification may be mandatory or optional in different countries. For example, the UK is one of 81 countries which has mandatory iron fortification of wheat flour (Hurrell, 2021). Many breakfast cereals, which are likely to be consumed by many primary school-age children, are fortified on a voluntary basis. UK National Diet and Nutrition Survey data shows impacts of breakfast consumption on micronutrient intakes; as the frequency of breakfast consumption increased, so did the percentage of children meeting the LRNI and RNI for iron. For example, when children ate breakfast daily, 58.5% met the RNI for iron compared to only 19.4% who skipped breakfast every day (Coulthard et al., 2017) and 27% of females who consumed the least breakfast cereal had iron intakes below LRNI, compared with only 5% of females who consumed the most cereal (Gibson, 2003). It is also noted that fortified cereals are more likely to be consumed by younger children, likely due to greater parental supervision (Coulthard et al., 2017) so as children get older and stop eating as much breakfast cereal, this can negatively impact their micronutrient status, including iron intake. People in the UK gain high proportions of their daily dietary iron from fortified

cereals and breads (Finnamore et al., 2014), but in other countries this is not necessarily the case. In Thailand, cereals are not routinely fortified with iron, which may explain the lowest iron intakes reported in the study by Rojroongwasinkul et al. (2013), whereas in Tanzania, where iron intakes were the highest reported in the study by Tatala et al. (2004), cereals are fortified with iron (Food Fortification Initiative, 2025). National food composition tables commonly include mandatory iron fortified foods but not optional fortification, so this could in part explain the differences in dietary iron intake between the studies.

Many studies collected socioeconomic data about subjects, and whilst there was no obvious correlation between economic status of the country and iron intake, some studies did report higher iron intakes in children from higher socioeconomic households; for example Shell-Duncan and McDade (2005) found that children in economically sufficient households had greater access to iron-rich foods including meat, though males were preferentially allocated these foods, resulting in higher ID in females regardless of wealth. Adamson et al. (1992) found no correlation between social group and iron intake, but Shell-Duncan and McDade (2005) found that economic status of subjects in one town was a significant predictor of ID. Donin at al. (2010) reported marked ethnic differences in nutritional intake of 9-10 year-olds in the UK, with Black Afro-Caribbean children having lower iron intake than white Europeans but South Asians having higher iron intake. This suggests that nutrient intake closely reflects varying dietary patterns in children of different ethnicities.

4.5 Iron intake compared to DRV

Three quarters of the studies compared actual iron intake with DRVs. Very large differences were seen in the iron intake as a percentage of the reference intake, both within countries (e.g. 39% to 131% in the same UK study), and between counties (36% in India to 339% in UAE). These differences did depend on differences in gender and age of the children studied and are also likely to depend on country specific factors.

6 studies reported that all primary school-age groups had a mean iron intake below that recommended, percentages varying from 36% to 98%, indicating that although some children are only receiving just below the reference intake, others are receiving far less iron in their diet than required, and are therefore at great risk of ID. There are potentially a wide range of reasons why children are not receiving enough iron in their diet. These may include socioeconomic status, food security, ethnicity, veganism and vegetarianism, and lack of consumption of iron-rich and iron-fortified foods and drinks. Ayogu et al. (2015) suggest that Nigerian children skipping breakfast and eating plant sources of iron with low bioavailability may account for below recommended iron intake.

Iron intakes below the recommended values do not necessarily indicate ID since reference intake values exceed the mean requirement or have been estimated too high, a concept suggested by Eussen et al. (2015) who found that whilst 50% of 6-12 month children had inadequate iron intakes, only 25% were ID. However, iron intakes below recommended values can be useful in indicating potential deficiency, especially if the difference between mean intake and reference value is large. True deficiency status should be diagnosed by other methods, and indeed many of the studies reviewed carried out biochemical

blood analysis for this reason. The WHO estimates half of anaemias are caused by nutritional ID (Petry et al., 2016) though the WHO does state that ID is more common in pre-school children and women of reproductive age (rather than primary school-age children) and that the contribution of iron intake to ID varies between population groups, with other factors including inherited blood disorders, malaria and parasitic infections known to influence ID too (Petry et al., 2016). Since ID is known to negatively affect children's cognitive development, some studies have examined the impacts of iron supplementation on school-age children's cognitive development, finding supplementation to have positive impacts on memory, attention, concentration and intelligence (Gutema et al., 2023).

In only 4 studies was it reported that the mean or median iron intake was above the daily iron recommendation for all age groups within that study. This included one study from each of UAE, Nigeria, UK and Tanzania, the former of which was the study by Ali et al. (2013) which had the lowest reference values but iron intake up to 339% of EAR, and the latter of which was the study by Tatala et al. (2004) which had the second highest reference values. There are potential ill effects of elevated iron intake which can lead to secondary iron overload, which, if prolonged, can cause negative health effects, especially on the liver where excess iron may be deposited (McDowell and Sticco, 2020). However, since the studies reviewed were only short-term studies, and the RoB assessment showed no follow up for any of the studies, it would be hard to predict if the children were at risk of iron overload, though children in the UAE appear to have 2 or 3 times more iron than recommended so may have increased risk.

5 studies reported that, for some age categories or genders, iron intake was above reference values but for others it was below. In these 5 studies it was more likely that older children were below recommended iron intake than younger children which may be because as children age, they often gain more control over their food choices, potentially leading to less balanced diets and fewer iron-rich foods. In addition, it was more common for females than males to have inadequate iron intake, which could be due to the higher iron intake seen in males, the higher iron requirements of females (only shown for 11-14 year-old females in the study by Thane et al., 2003) or the differing dietary patterns between genders. For example, Glynn et al. (2005) reported males ate more breakfast cereals (typically iron fortified) and baked beans (a source of non-haem iron) than females and offered this as an explanation for higher iron intakes in males than females.

4.6 Limitations of this review

In addition to those already mentioned, there are several other limitations to this review, largely due to the heterogeneous methods used in the studies.

- Children's diets tend to be highly variable from one day to another, so the fact that food intakes were recorded over a period of just a few days in most studies means that food reporting may not be very representative of the whole child's diet. Seasonal variations in diet were also not always accounted for.
- Some studies focussed on a limited geographical area, meaning results were not necessarily representative of the whole country.

- In some studies, the children themselves recalled their food intake but in other studies parents or carers were requested to recall what their children ate, and they might have been unaware of some foods their children were eating.
- The length of food diaries / FFQ varied between studies. Food records used in the studies were mostly unweighted, which, although reducing participant burden, can introduce more variability and potential inaccuracies. Additionally, the FFQs may not have been properly validated to measure children's iron intake.
- Different software packages were used by study authors to calculate nutrient intake (e.g. Jennings (2010) uses Dietplan5 but Glynn at al. (2005) uses DIDO).
- Several studies did not give raw data on DRVs creating challenges for comparison.
- There was no follow up in most studies so health outcomes for children were not assessed.
- The age ranges of children in studies don't always match reference value categories and age categories also varied between studies making direct comparisons difficult.
- Many previous studies have looked at iron intake in infants, rather than primary age children, making comparisons with previous studies difficult and some studies looked at children in very broad age categories e.g. 1-18 years or in categories which did not fit easily within primary age window e.g. 3-6 years.
- The studies reviewed had no information available on the form of iron (haem or non-haem) or the presence of enhancers or inhibitors of iron absorption in the diet, which are important factors in determining iron bioavailability.
- The studies did not always correct for over or under-reporting of iron intake.

5. Conclusion

There is strong interest in the quality of children's diets and the impacts of these on current and future health. This review demonstrates that, worldwide, dietary iron intake of primary school-age children does not consistently align with DRVs, and that there is wide variability in both DRVs and iron intake. Disparities in DRVs reflect the fact that some countries base these on promoting optimum health and well-being, whilst others are more focussed on addressing problems associated with iron bioavailability, iron status and malnutrition. Large variations in iron intake reflect differences in dietary habits, bioavailability, fortification, ethnicity and socioeconomic status. Further research is needed to obtain consensus in the use of DRVs and to establish more data on iron bioavailability in children. Worldwide alignment of DRVs for primary school-age children, which are based on up-to-date scientific data, is urgently needed. Implementing common standardised dietary assessment methods and standardised food composition tables would aid more reliable comparison of dietary intake within and between countries.

Whilst many children have adequate iron intake, a large proportion do not, increasing their risk of ID and subsequent consequences, so children's health programmes should focus on iron malnutrition. This could include educating children and parents on iron-rich and iron-fortified food choices and encouraging iron

supplementation where iron intakes are lowest. Policy makers should develop more targeted interventions for populations with iron intake falling below reference values, and longitudinal studies examining the long-term impacts of dietary ID in children are recommended.

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