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Nutrient Reference Values for Australia and New Zealand
Including Recommended Dietary Intakes

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IRON

BACKGROUND

Iron is a component of a number of proteins including haemoglobin, myoglobin, cytochromes and enzymes involved in redox reactions. Haemoglobin is important for transport of oxygen to tissues throughout the body. Iron can exist in a range of oxidation states. The interconversion of these various oxidation states allows iron to bind reversibly to ligands such as oxygen, nitrogen and sulphur atoms. Almost two thirds of the body's iron is found in haemoglobin in circulating erythrocytes. About a quarter of the body's iron is found in readily metabolised stores as ferritin or haemosiderin in the liver and reticulo-endothelial system. The remaining iron is in the myoglobin of muscle tissue and a variety of enzymes necessary for oxidative metabolism and other cell functions.

The iron content of the body is highly conserved (Bothwell et al 1979). To achieve iron balance, adult men need to absorb about 1 mg/day and adult menstruating women about 1.5 mg/day, although this is highly variable. Towards the end of pregnancy, the absorption of 4–5 mg/day is necessary. Requirements are higher during periods of rapid growth in early childhood and adolescence.

Inadequate iron intake can lead to varying degrees of deficiency, from low iron stores (as indicated by low serum ferritin and a decrease in iron-binding capacity); to early iron deficiency (decreased serum transferrin saturation; increased erythrocyte protoporphyrin concentration and increased serum transferrin receptor) to iron-deficiency anaemia (low haemoglobin and haematocrit as well as reduced mean corpuscular haemoglobin and volume). These biochemical measures are used as the key indicators in setting the iron requirements.

Wholegrain cereals, meats, fish and poultry are the major contributors to iron intake in Australia and New Zealand, but the iron from plant sources is less bioavailable. The form in which iron is consumed will affect dietary intake requirements as not all dietary iron is equally available to the body. The factors that determine the proportion of iron absorbed from food are complex. They include the iron status of an individual, as well as the iron content and composition of a meal. Normal absorption may vary from 50% in breast milk to 10% or less in infant cereals. Iron in foods can come in two general forms – as haem or non-haem iron. Iron from animal food sources such as meat, fish and poultry may be either haem or non-haem whereas the iron in plant sources such grains and vegetables is non-haem. The haem form is more bioavailable to humans than the non-haem.

The presence of other nutrients such as vitamin C and organic acids such as citric, lactic or malic acid can increase the absorption of non-haem iron. Consumption of meat, fish and poultry can also increase non-haem iron absorption from plant foods consumed at the same time. In contrast, some other components of the food supply such as calcium, zinc or phytates (found in legumes, rice and other grains) can inhibit the absorption of both haem and non-haem iron, and polyphenols and vegetable protein can inhibit absorption of non-haem iron. High iron intakes can, in turn, affect the absorption of other nutrients such as zinc or calcium.

Functional indicators of iron deficiency may include reduced physical work capacity, delayed psychomotor development in infants, impaired cognitive function, impaired immunity and adverse pregnancy outcomes. However, as these are difficult to relate directly to a specific dietary intake, biochemical indices are generally used in estimating dietary requirements.

The distribution of iron requirements is skewed to the right and it is difficult to achieve a steady state with iron because it is highly conserved in the body. For these reasons, factorial modelling rather than the classical balance study method is used to determine the average requirements for the various age, gender and physiological states. This factorial modelling proposes daily physiological requirement for absorbed iron based on estimates of basal losses (obligatory losses through faeces, urine, sweat and exfoliation of skin) and, where relevant, menstrual losses and needs for iron accretion in periods of growth such as childhood, adolescence or pregnancy (FNB:IOM 2001). These accretion needs are estimated from known changes in blood volume, fetal and placental iron concentration and increases in total body erythrocyte mass. The EARs are based on the need to maintain a normal, functional iron concentration, but only a small store (serum ferritin concentration of 15 μg/L).

1 mmol iron = 55.8 mg iron

RECOMMENDATIONS BY LIFE STAGE AND GENDER

Infants	**AI**	**Iron**
0–6 months	**0.2 mg/day**	

***Rationale*:** The AI for 0–6 months was calculated by multiplying the average intake of breast milk (0.78 L/day) by the average concentration of iron in breast milk (0.26 mg/L), and rounding (Butte et al 1987, Dewey & Lonnerdal 1983, Lipsman et al 1985, Picciano & Guthrie 1976, Vaughan et al 1979).

***Note*:** this recommendation relates to breast-fed babies. The iron in formula is much less bioavailable (generally only 10–20% as available as that in breast milk) (Fomon et al 1993, Lonnerdal et al 1981) so the intake in formula-fed infants will need to be significantly higher.

Infants	**EAR**	**RDI**	**Iron**
7–12 months	**7 mg/day**	**11 mg/day**	

Rationale: The EAR for 7–12 months was set by modelling the components of iron requirements, estimating the requirements for absorbed iron at the 50th centile with use of an upper limit of 10% iron absorption, and rounding. The RDI was set by modelling the components of iron requirements, estimating the requirement for absorbed iron at the 97.5th centile, with use of an upper limit of 10% absorption, and rounding.

Absorption is about 18% from a mixed western diet including animal foods and about 10% from a vegetarian diet; so vegetarian infants will need higher intakes.

Children & adolescents	**EAR**	**RDI**	**Iron**
All			
1–3 yr	**4 mg/day**	**9 mg/day**	
4–8 yr	**4 mg/day**	**10 mg/day**	
Boys			
9–13 yr	**6 mg/day**	**8 mg/day**	
14–18 yr	**8 mg/day**	**11 mg/day**	
Girls			
9–13 yr	**6 mg/day**	**8 mg/day**	
14–18 yr	**8 mg/day**	**15 mg/day**	

***Rationale*:** The EAR for children was set by modelling the components of iron requirements, estimating the requirements for absorbed iron at the 50th centile with use of an upper limit of 14% iron absorption for 1–3-year-olds and 18% at other ages, and rounding (FNB:IOM 2001). The RDI was set by modelling the components of iron requirements, estimating the requirement for absorbed iron at the 97.5th centile, with use of an upper limit of 14% absorption for 1–3-year-olds and 18% for other ages, and rounding.

In setting the EAR and RDI for girls, it was assumed that those younger than 14 years do not menstruate and that all girls 14 years and older do menstruate. The lower RDI for children aged 9–13 year compared to those aged 1–8 year despite the higher EAR reflects the very high variability in requirements within the younger age groups. Absorption is about 18% from a mixed western diet including animal foods and about 10% from a vegetarian diet; so vegetarians will need intakes about 80% higher.

Adults	**EAR**	**RDI**	**Iron**
Men			
19–30 yr	**6 mg/day**	**8 mg/day**	
31–50 yr	**6 mg/day**	**8 mg/day**	
51–70 yr	**6 mg/day**	**8 mg/day**	
>70 yr	**6 mg/day**	**8 mg/day**	
Women			
19–30 yr	**8 mg/day**	**18 mg/day**	
31–50 yr	**8 mg/day**	**18 mg/day**	
51–70 yr	**5 mg/day**	**8 mg/day**	
>70 yr	**5 mg/day**	**8 mg/day**	

***Rationale*:** The EARs for adults were set by modelling the components of iron requirements, estimating the requirements for absorbed iron at the 50th centile with use of an upper limit of 18% iron absorption, and rounding (FNB:IOM 2001). The RDI was set by modelling the components of iron requirements, estimating the requirement for absorbed iron at the 97.5th centile, with use of an upper limit of 18% iron absorption and rounding. The large difference between the EAR and the RDI in women aged from 19–50 years reflects high variability in needs related to variability in menstrual losses. In setting the EARs and RDIs for women, it was assumed that women over 50 years do not menstruate. Absorption is about 18% from a mixed western diet including animal foods and about 10% from a vegetarian diet; so vegetarians will need intakes about 80% higher.

Pregnancy	**EAR**	**RDI**	**Iron**
14–18 yr	**23 mg/day**	**27 mg/day**	
19–30 yr	**22 mg/day**	**27 mg/day**	
31–50 yr	**22 mg/day**	**27 mg/day**	

***Rationale*:** The EAR and RDI were established using estimates for the third trimester to build iron stores during the first trimester of pregnancy. The EAR was set by modelling the components of iron requirements for absorbed iron for the 50th centile and the RDI by modelling the 97.5th centile, and using an upper limit of 25% iron absorption, and rounding. Absorption is about 18% from a mixed western diet including animal foods and about 10% from a vegetarian diet; so vegetarians will need intakes about 80% higher.

Lactation	**EAR**	**RDI**	**Iron**
14–18 yr	**7.0 mg/day**	**10 mg/day**	
19–30 yr	**6.5 mg/day**	**9 mg/day**	
31–50 yr	**6.5 mg/day**	**9 mg/day**	

***Rationale*:** To estimate total iron requirement for lactation, iron secreted in milk and basal iron loss were added by simulated distribution (FNB:IOM 2001). An allowance for maternal growth needs was also made for adolescent mothers. The resultant distribution of iron need, assuming absorption of 18%, was used to estimate EARs and RDIs. The variability of requirement was based on basal needs modelled as for non-lactating women and milk secretion modelling with a CV of 30% for the EAR. These estimations assume that menstruation does not resume until after 6 months of exclusive breastfeeding. Absorption is about 18% from a mixed western diet including animal foods and about 10% from a vegetarian diet; so vegetarians will need intakes about 80% higher.

UPPER LEVEL OF INTAKE - IRON

Infants	
0–12 months	**20 mg/day**
Children and adolescents	
1–3 yr	**20 mg/day**
4–8 yr	**40 mg/day**
9–13 yr	**40 mg/day**
14–18 yr	**45 mg/day**
Adults 19+ yr	
Men	**45 mg/day**
Women	**45 mg/day**
Pregnancy	
14–18 yr	**45 mg/day**
19–50 yr	**45 mg/day**
Lactation	
14–18 yr	**45 mg/day**
19–50 yr	**45 mg/day**

***Rationale*:** Severity of toxicity is related to the amount of elemental iron absorbed and can range from gastrointestinal irritation to systemic toxicity. For adults, based on gastrointestinal symptoms, a LOAEL of 70 mg/day was set based on the level assessed as safe from the supplemental study of Frykman et al (1994) plus the median population dietary intakes (FNB:IOM 2001). Because of the self-limiting nature of the adverse outcomes, a relatively low UF of 1.5 was used to extrapolate from the LOAEL to the NOAEL, giving a UL of 45 mg/day after rounding. As data are limited for pregnancy and lactation, the same figure was applied to these groups.

For infants and young children, a UF of 3 was used to extrapolate from the LOAEL to the NOAEL based on potential adverse growth effects (Dewey et al 2002), giving a figure of 20 mg/day.

As the safety of excess supplemental non-haem iron in children from 4–18 years has not been studied, a UL of 40 mg/day was set for children aged 4–13 years and the adult UL of 45 mg was set for adolescents.

***Note*:** Up to 0.5% of the Caucasian population is homozygous for hereditary haemochromatosis and, as a result, particularly susceptible to iron overload, even at normal dietary iron intakes. Such individuals should avoid iron supplements and highly iron-fortified foods. The majority of homozygotes are not diagnosed or identified until sufficient iron has accumulated to produce adverse effects.

REFERENCES

Bothwell TH, Charlton RW, Cook JD, Finch CA. *Iron metabolism in man.* Oxford: Blackwell Scientific, 1979.

Butte NF, Garza C, Smith EO, Wills C, Nichols BL. Macro- and trace-mineral intakes of exclusively breast-fed infants. *Am J Clin Nutr* 1987;45:42–8.

Dewey KG, Domellof M, Cohen RJ, Landa Rivera L, Hernell O, Lonnerdal B. Iron supplementation affects growth and morbidity of breast-fed infants: results of a randomized trial in Sweden and Honduras. *J Nutr* 2002;132:3249–55.

Dewey KG, Lonnerdal B. Milk and nutrient intake of breast-fed infants from 1-6 months: Relation to growth and fatness. *J Pediatr Gastroenterol Nutr* 1983;2:497–506.

Fomon SJ, Ziegler EE, Nelson SE. Erythrocyte incorporation of ingested ^{58}Fe by 56-day-old breast-fed and formula-fed infants. *Pediatr Res* 1993;33:573–6.

Food and Nutrition Board: Institute of Medicine. *Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, manganese, Molybdenum, Nickel, Silicon, Vanadium and Zinc.* Washington DC: National Academy Press, 2001.

Frykman E, Bystrom M, Jansson U, Edberg A, Hansen T. Side effects of iron supplements in blood donors: Superior tolerance of heme iron. *J Lab Clin Med* 1994;123:561–4.

Lipsman S, Dewey KG, Lonnerdal B. Breast feeding among teenage mothers: Milk composition, infant growth, and maternal dietary intake. *J Paediatr Gastroenterol Nutr* 1985;4:426–34.

Lonnerdal B, Keen CL, Hurley LS. Iron, copper, zinc and manganese in milk. *Ann Rev Nutr* 1981;1:149–74.

Picciano MF, Guthrie HA. Copper, iron and zinc contents of mature human milk. *Am J Clin Nutr* 1976;29:242–54.

Vaughan LA, Weber CW, Kemberling SR. Longitudinal changes in the mineral content of human milk. *Am J Clin Nutr* 1979;32:2301–6.