IRON ABSORPTION

SPOTLIGHT ON IRON

Iron is a mineral found in every cell in the body. It is vital for both physical and mental well-being. Iron has three main functions:

- Oxygen delivery and utilisation in and around the body
- Maintaining a healthy immune system
- Aiding energy production

Insufficient dietary iron can result in iron deficiency erythropoiesis (ID) or can progress to iron deficiency anaemia (IDA). There are several symptoms associated with these conditions as seen in the table to the right.

In Adults	In Children
• Fatigue and lethargy • Pale skin • Heart palpitations • Shortness of breath • Poor concentration • Reduced resistance to cold • Frequent infections • Spoon-shaped nails • Restless legs syndrome • Pica (desire to eat non-food items) • Difficulty swallowing	• Tiredness or lethargy • Pale skin • Grumpiness or irritability • Always getting sick • Slow growth • Difficulty sleeping • Feels the cold • Pica (desire to eat non-food items)

Note: One may not present with all of these symptoms. Source: Zimmerman et al (2007)[1] and United Kingdom National Health Service (2018)[2].

ID and IDA are the most frequent global nutritional disorders that affects up to a third of the world's population[3]. In New Zealand 8 out of 10 toddlers are not meeting the recommended daily iron intake[5] and 14% of children under the age of 2 have ID[6]. If left untreated ID can contribute to impaired physical, mental and behavioural development in children[1].

For older children and adults, the last New Zealand adult national nutrition survey showed over a third of teenage girls aged 15-18 years do not achieve their daily iron requirements and 1 in 14 adult women over 15 years old are low in iron[4]. ID and IDA in adults have been associated with increased risk of infection, heart and lung complications, pregnancy complications and impaired exercise and work performance[2].

HAEM IRON EXAMPLES

NON-HAEM IRON EXAMPLES

TYPES OF IRON

THERE ARE TWO MAIN TYPES OF IRON IN FOOD WHICH ARE ABSORBED VERY DIFFERENTLY:

HAEM IRON

- Haem iron is naturally only found in meat tissue (e.g. red meat, fish† and poultry)[7].
- The iron in meat is approximately 40-85% haem iron, with red meat being at the upper end of the range (with the exclusion of mussels) and white meat being at the lower end. The remaining iron content is non-haem iron[8].
- Plant foods do not contain haem iron[9].
- Haem iron is better absorbed than non-haem iron and is relatively unaffected by other factors[10]. The general absorption of haem iron is between 15-35% with an average of 25%[11,12]. However, at times the body can absorb up to or greater than 40%.
- In an omnivorous diet, haem iron makes up approximately 10–15% of iron intake, yet it can contribute up to 40% or more of the total iron absorbed by the body[13]. This is because it has a higher absorptive capacity.
- Low haem iron in the diet has been associated with an increased risk of ID in New Zealand females[14] and children overseas[15,16].

† - *refer to end of reference list*

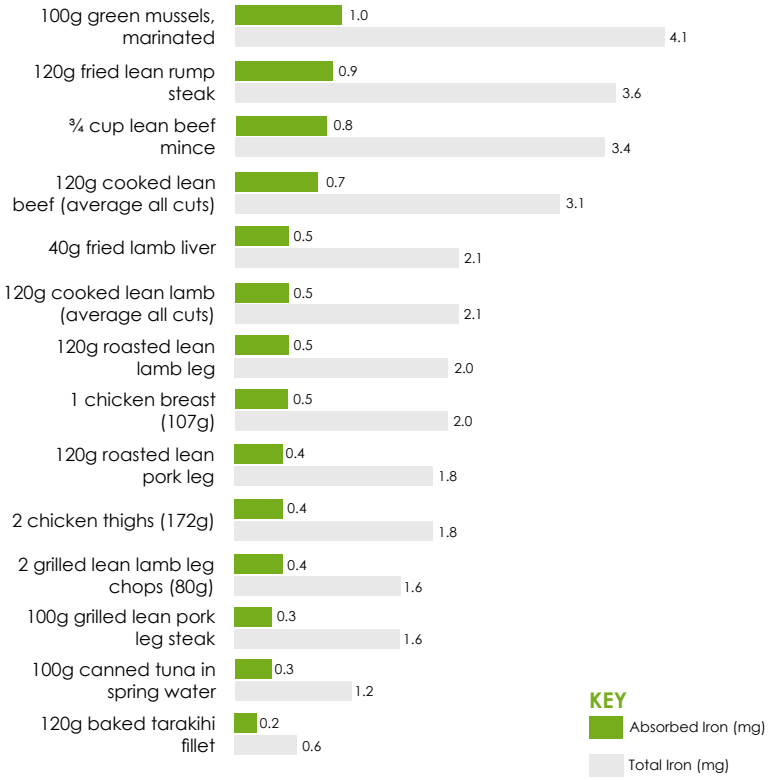
NON-HAEM IRON

- Non-haem iron is found in both plant-derived foods (e.g. cereals, legumes, fruits and vegetables) and meat[9]. It is the only iron source in plant foods[9].
- Most of the iron consumed in the diet is from non-haem sources, however it is not as well absorbed as haem iron and can be easily inhibited by other nutrients[10].
- The general absorption of non-haem iron is between 5-12%, with an average of 8%[11,13,17].

Soy leghemoglobin (Soy LgHb) is a newly created, plant-derived haem iron source that is used in foods produced by Impossible Foods. Soy LgHb is produced from genetically modification technology where it is extracted from soy plant root nodules and expressed on yeast cells. There is limited evidence to prove its nutrition equivalence to myoglobin in meat[18].

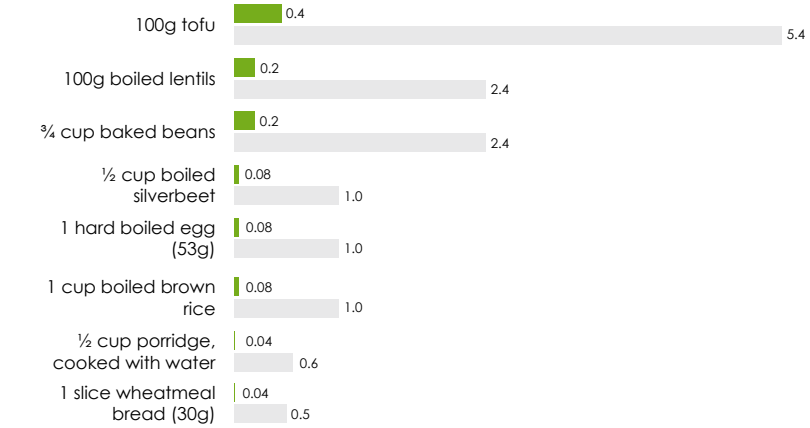
HAEM IRON FOODS

- Best absorbed (typically 25%[11,12])



NON-HAEM IRON FOODS

- Less absorbed (typically 8%[11,13,17])



Source: The Concise New Zealand Food Composition Tables, 13 edition (2018)[53].

RECOMMENDED DIETARY IRON INTAKE

Population group	mg iron per day
Infants (7-12 months)	11
Children (1-13 years)	8-10
Boys (14-18 years)	11
Girls (14-18 years)	15
Women (19-50 years)	18
Pregnant women	27
Breastfeeding women	9-10
Women over 50 years	8
Men over 19 years	8

Source: Nutrient Reference Values for Australia and New Zealand[19].

As mentioned in the above section, thousands of New Zealanders are not meeting their iron requirements, particularly children and young women[4-6]. This is extremely concerning at both an individual health level, and a population health level in terms of potential impairment of physical, mental and behavioural development in children[1] and risk of adverse physical work productivity, immunity, heart health and pregnancy outcomes in adults[2].

DETERMINANTS OF IRON ABSORPTION

The amount of iron that can be absorbed can vary significantly due to:

- **An individual's iron status:** When the body needs more iron, more is absorbed, whereas less iron is absorbed when levels are adequate[9]. Scientific research shows absorption rates can vary up to 5% in an individual with adequate and healthy iron stores and up to or greater than 40% in an individual with depleted or low iron stores[11-13]. Iron status may be influenced by blood loss, genetics, ethnicity, medications (e.g. omeprazole), infection, exercise and possible inflammation associated with obesity[20,21].
- **The amount of dietary iron consumed:** Individuals who obtain more iron in their diet (through naturally iron-rich foods, fortified foods or supplementation) are predisposing themselves to absorb more iron[1].
- **The type of iron consumed:** As mentioned in the above section, iron absorption is very different in animal and plant foods. Haem iron (from lean red meat, fish† and poultry) is much better absorbed than the non-haem iron from plant foods[10].
- **The presence of iron inhibitors or enhancers:** An inhibitor will decrease the amount of iron being absorbed from food and an enhancer will increase the amount of iron absorbed[9]. Non-haem iron absorption is more easily enhanced and inhibited than haem iron due to different absorption mechanisms[10,13]. See the enhancers and inhibitors of non-haem iron absorption section below.
- **Timing of dietary iron consumption:** Typically 3-6 hours after strenuous exercise there is a peak in hepcidin which can impair iron absorption[22]. Hepcidin is a hormone that controls iron metabolism and use in the body. For more information on hepcidin check out the Hepciden fact sheet here.

Haemochromatosis, commonly known as iron overload, is a genetic condition that affects 1 in 200 New Zealanders[23]. It occurs when a person stores too much iron from the diet which can lead to heart, liver and pancreas damage. Some of the early symptoms of iron overload can be confused with other common health conditions, including ID. This means it is important to determine iron status via a blood test before taking iron supplements. Iron overload is treated with regular blood removal.

ENHANCERS OF NON-HAEM IRON ABSORPTION

MEAT, FISH† AND POULTRY

Red meat, fish† and poultry can enhance iron status in two ways:

- By providing easily absorbable haem iron.
- By increasing the bioavailability (the amount that can be absorbed) from non-haem iron sources, such as cereals, legumes, fruit and vegetables.

Animal protein from red meat, fish† and poultry (MFP) can increase non-haem iron absorption by up to three-fold[24]. The mechanism for this has not been established, however there is a proposed mechanism called the MFP factor. It is believed that the protein component of muscle tissue in MFP binds to iron forming soluble complexes, making non-haem iron more available for absorption[25].

Not all foods of animal origin have the same effect as meat protein to enhance non-haem iron absorption. For example, animal proteins in milk, dairy products and eggs show no enhancing effect to date[25,26].

VITAMIN C (ASCORBIC ACID)

Vitamin C has been shown to increase the absorption of non-haem iron by two to three-fold[27,28]. There is a dose-related effect, whereby the higher the vitamin C content of a meal, the greater the iron absorption. This effect is seen with vitamin C concentrations of up to 100mg in a meal[28]. Interestingly, vitamin C can also counteract the effects of iron inhibitors[29] (see the inhibitors of non-haem iron absorption section below). As a result, it is advised foods that are a good source of vitamin C are incorporated into meals. These include but are not limited to:

Fruits	Vegetables
• Kiwifruit	• Capsicum
• Citrus fruits	• Tomatoes
• Grapes	• Broccoli
• Feijoas	• Potato
• Tamarillos	• Cauliflower
• Cherries	• Pumpkin
• Pineapple	• Cabbage
• Orange juice	

Source: Plant and Food Research and Ministry of Health (2018)[53].

INHIBITORS OF NON-HAEM IRON ABSORPTION

The factors that inhibit non-haem iron absorption are mainly present in plant foods[30]. These include:

- Polyphenols (e.g. tannins in tea, coffee, wine and cocoa)
- Phytates (e.g. legumes, nuts, wholegrain cereals, unprocessed bran)
- Soy protein (e.g. tofu)
- Dietary fibre (e.g. excessive quantities of wheat bran, oats)
- Calcium* (e.g. milk, cheese, yoghurt)

Although these food components can play important roles in health, they can have a negative impact on iron absorption. To optimise iron absorption these food components should be carefully timed and minimised prior to, during or after consumption of iron-rich foods[9]. For example, avoid drinking tea and coffee one to two hours before and after meals.

*Iron from breast milk is highly bioavailable, despite it being high in calcium. This along with other benefits for mother and baby's well-being is why exclusive breastfeeding up to six months is recommended[31].

Nutrition advice for infants and young children[31,38]

- Exclusive breast feeding, when possible, is recommended up to 6 months of age with complementary foods introduced around 6 months alongside milk feeds
- Include a variety of fruit and vegetables in the diet, especially those high in vitamin C
- Include lean red meat, fish and poultry in the diet (in the appropriate texture) to increase iron intake and to improve non-haem iron absorption
- Pair vitamin C rich foods with non-haem foods
- Choose iron-fortified breakfast cereals
- Avoid giving tea and coffee to infants and young children
- Avoid giving cows' milk during the first year of life
- Seek professional medical and nutritional advice if you are choosing a vegetarian or vegan diet for your child

GROUPS VULNERABLE TO IRON DEFICIENCY

INFANTS AND YOUNG CHILDREN

Full-term infants are generally born with sufficient iron stores to meet their needs for the first 6 months of life[31]. However, New Zealand research of 131 newborn infants showed 7% had ID, suggesting not all full-term infants are born with sufficient iron stores if maternal iron status is low[32]. Iron transfer to the foetus occurs mainly in late gestation, therefore pre-term babies (babies born before 37 weeks) are at particular risk of iron deficiency[33].

Breast milk is not particularly high in iron (0.35mg/L), but its iron content is highly bioavailable (50% can be absorbed)[34]. Infant formula is fortified with iron and can also provide a sufficient iron supply.

For complementary feeding (introducing foods to babies in addition to milk feeds), iron-rich foods are recommended as a first food[31]. Including lean meat (in an appropriate texture) and iron-fortified cereals as complementary foods have been associated with a reduced risk of ID[35,36].

When iron-rich foods are given with vitamin C the iron absorption can almost double[37]. Plain cows' milk, as a substitute for breast milk, is not recommended for infants under the age of one as it does not contain sufficient iron to meet the needs of infants[31].

PREGNANT WOMEN

It is estimated 40% of pregnant women worldwide have IDA[39]. During pregnancy iron requirements can increase by as much as 80% to support the growing foetus and placenta and the maternal increase in blood volume and total red cell mass[19]. To help compensate for this, the body can increase iron absorption capacity by three-fold[40].

ID in pregnancy is linked with increased risk of complications including a higher risk of babies being born pre-term, small for gestational age and/or with low birth weights[41-43]. This can cause damage to babies' red blood cells and increases the risk of infection for baby[41,43], as well as an increased risk of foetal and maternal morbidity and mortality[42].

Nutrition advice for pregnant and breastfeeding women[44]

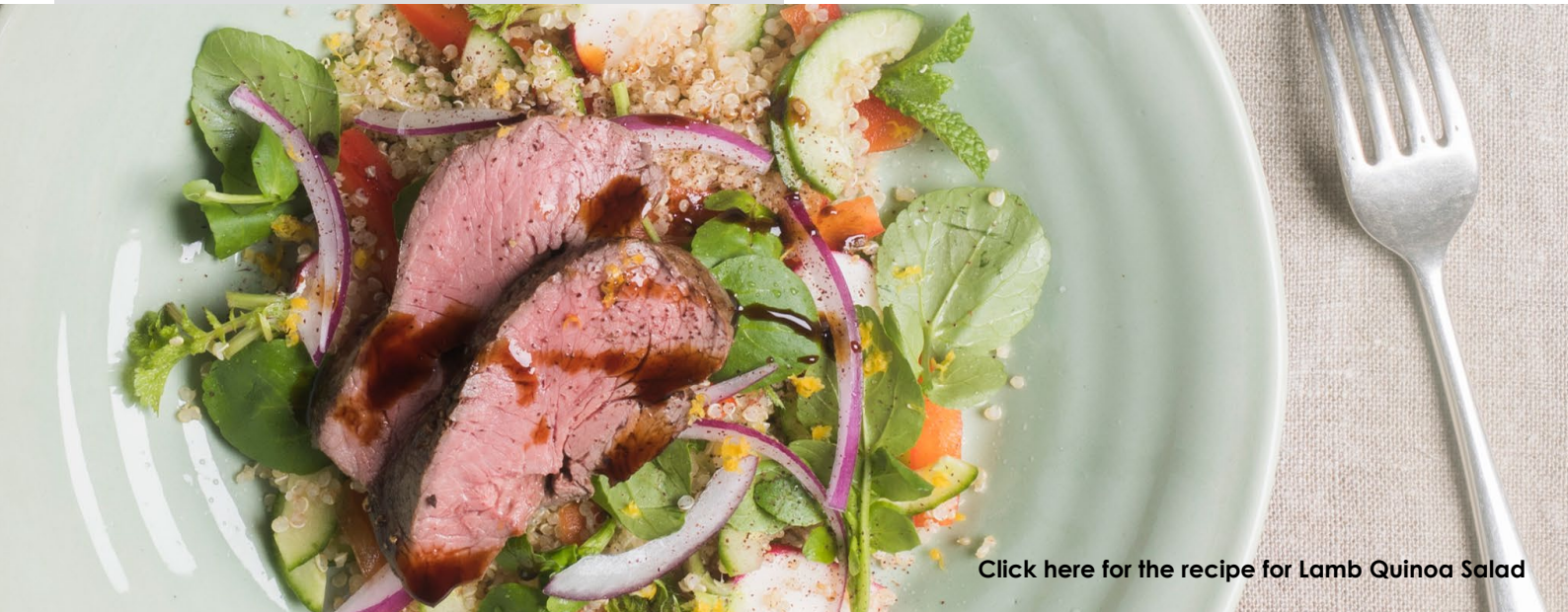
- Choose a wide variety of foods, including iron-rich and vitamin C-rich foods
- Eat at least two servings of lean red meat, poultry, seafood, eggs, nuts and seeds or legumes per day
- Pair vitamin C rich foods with non-haem foods
- Seek professional medical and nutritional advice if you are choosing a vegetarian or vegan diet during pregnancy
- Avoid drinking tea and coffee one to two hours before and after meals

VEGETARIANS AND VEGANS

Although vegetarian and vegan diets are often higher in total iron, individuals on these diets can be at an increased risk of ID[45,46] as the plant-derived non-haem iron is more poorly absorbed than haem iron from animal sources. In addition, these diets are typically high in cereals, legumes, phytates, soy and polyphenols – all of which can inhibit iron absorption. Iron-inhibiting foods should be carefully timed and ideally minimised before, during and after meals (e.g. tea). Blood markers should be closely monitored and reviewed to see whether iron status improves or worsens. Current nutrient reference values for Australia and New Zealand indicate that vegetarians will require about 80% more dietary iron as compared to a normal Western diet[19].

Nutrition advice for vegetarians and vegans:

- Vegetarians and vegans can still meet their iron requirements, however careful planning and consideration is required. It is advised to seek professional advice from a Registered Dietitian or Registered Nutritionist
- Plan meals carefully to incorporate vitamin C rich foods with non-haem iron foods, such as having spinach with lentils or having orange juice with iron-fortified cereal
- Avoid consuming iron inhibitors prior to, during and after meals (e.g. tea and coffee)
- Choose iron-fortified breakfast cereals and spreads
- Where possible, choose fermented soy foods over normal soy proteins, such as tempeh and miso as the iron from these are typically more bioavailable
- Supplementation may be required for certain nutrients (e.g. vitamin B_{12}) under medical supervision. Seek advice from your GP



Click here for the recipe for Lamb Quinoa Salad

ATHLETES

Heavy exercise increases iron requirements due to increased exercise-induced iron loss (through sweat and gastrointestinal blood loss); increases in hepcidin post exercise and athletes not obtaining enough dietary iron through inadequate nutritional intake[22,47]. IDA in athletes is associated with impaired VO_2 max (a measure of aerobic endurance) and decreased energy efficiency, which impairs athletic performance[48].

It is important to note that a condition known as sports anaemia can occur in athletes and is a normal adaptation to intense training. Sports anaemia is the expansion in plasma volume with exercise training that results in the dilution of blood cell mass, so may temporarily reduce the concentration of haemoglobin in the blood. However, this is a temporary state and corrected as the body adapts to training and does not require iron supplementation[49]. To differentiate between sports and normal anaemia, serum ferritin (and other markers of iron status, such as soluble transferrin receptor and total iron binding capacity) should be measured alongside haemoglobin levels[50]. In sports anaemia, no declines in markers of iron status should be seen, however a decline in haemoglobin will be noted.

Inflammation can increase by two-to-three-fold after strenuous or continuous exercise, and can impair iron absorption and recycling for three to six hours post-exercise[22]. As it is not uncommon practice for athletes to eat meals around this time, the effect of impaired iron absorption may be a significant contributing factor to the risk of iron deficiency in athletes.

Nutrition advice for athletes

- Note that when eating iron-rich food three to six hours after strenuous or prolonged exercise, there may be an impairment in iron absorption[22]
- If taking an iron supplement, try to take this immediately after exercise and in the morning to maximise iron absorption
- Ensure iron-rich meals and snacks are distributed throughout the day, preferably with enhancers
- Aim for 1.2-2g/kg/day of high-quality protein[51]. This could include lean red meat 3-4 times per week which is a good source of iron
- Athletes should be aware of the signs and symptoms of iron deficiency (see spotlight on iron section above) and should get a blood test if they are presenting with any of the issues. It is encouraged that athletes get iron blood screened two to three times a year
- Vegetarian and vegan athletes can still meet their iron requirements, however careful planning and consideration is required. It is advised to seek professional advice from a Registered Sports Dietitian or Registered Sports Nutritionist
- For more information see the Food and Sport webpage here.

IRON SUPPLEMENTS

The need for supplementation is dependent on the stage of iron deficiency. The stages of iron deficiency can be determined by common blood markers, such as serum ferritin, transferrin saturation and haemoglobin[50]. There are three main stages of iron deficiency, as seen in the table below.

Stages	Serum ferritin (ug/L)	Transferrin saturation (%)	Haemoglobin (g/L)
Iron depletion (stage 1)	Low	Normal	Normal
ID (stage 2)	Low	Low	Normal
IDA (stage 3)	Low	Low	Low

Source: The concepts of this table have been derived from Whitney et al (2011)[9] and Pfeiffer et al (2017)[50].

If a person presents with iron depletion (stage 1) nutritional intervention is recommended under medical and nutrition supervision[9]. For those that eat meat this would involve increasing the intake of haem-iron and non-haem iron foods. For vegetarians and vegans this would involve increasing the amount of non-haem foods. For meat eaters, vegetarians and vegans alike, vitamin C should be consumed at the time of having non-haem iron foods, whereas iron-inhibiting foods should be carefully timed and ideally minimised before, during and after meals (e.g. tea and coffee). Blood markers should be closely monitored and reviewed to see whether iron status is improving or worsening.

If a person presents with diagnosed iron deficiency and iron deficiency anaemia (stage 2 and 3, respectively) supplementation and nutritional intervention is recommended under medical and nutrition supervision[9]. Supplementation should be prioritised and food intake should be optimised to assist supplementation (e.g. including enhancers at meals and ideally minimising inhibitors). As with stage 1, blood markers should be closely monitored and reviewed to see whether iron status improves or worsens. Once stage 2 and stage 3 are corrected supplementation may not be required however, food intake should still aim to optimise iron absorption.

Iron supplements can cause adverse side effects (e.g. nausea, constipation, gastrointestinal) and can interfere with zinc and calcium absorption. Therefore, they should be timed accordingly. They should only be used when prescribed by a medical practitioner or a Registered Dietitian.

CONCLUSION

- Haem iron (found in red meat, fish† and poultry) is better absorbed than non-haem iron (found mainly in plant-derived foods)
- Including iron enhancers and minimising iron inhibitors at meals should be considered to optimise iron absorption
- Red meat, fish†, poultry and vitamin C can improve the absorption of non-haem iron
- Tannins, calcium, soy proteins, phytates and dietary fibre can all reduce the absorption of non-haem iron. Haem iron absorption is less affected by inhibitors
- For infants, exclusive breast feeding is encouraged for up to six months. The iron in breastmilk is well absorbed. Infant formula is fortified with iron and can also provide a sufficient iron supply
- From around the age of six months iron-rich foods, such as puréed meat and iron fortified cereals are recommended
- For low iron stores, or iron depletion, nutritional intervention is recommended. This should be done under medical and nutritional supervision
- For diagnosed ID and IDA supplementation and nutritional intervention is recommended to restore normal iron status. This should be done under medical and nutritional supervision.
- With careful food choices, groups at risk of iron deficiency (infants, pregnant and breastfeeding women, vegetarians, vegans and athletes) can improve the availability of iron in their diets

What does this mean for health professionals?

- Young children, pregnant and breastfeeding women, vegetarians, vegans and athletes in particular are at a higher risk of ID and IDA. It is imperative these groups get enough iron primarily through iron-rich foods, iron fortified foods and when medically necessary, supplementation
- Encourage people to eat iron-rich foods, such as lean red meat, fish, poultry or alternatives as part of a varied, balanced diet
- Up to 500g per week of cooked, lean red meat (equivalent to about 700-750g raw) is recommended by the Ministry of Health for adults[52]
- Those who do and do not eat meat should incorporate iron enhancers (e.g. vitamin C) into meals when eating non-haem iron foods
- Tea and coffee should only be consumed one to two hours before and after meals and is discouraged as a beverage for young children
- To restore normal iron status, supplementation and nutritional intervention is recommended for diagnosed ID and IDA. This is to be done under medical and nutritional supervision with regular monitoring
- For individuals presenting with iron depletion, or low iron, nutritional intervention is recommended under medical and nutritional supervision. This is to be monitored regularly

Click here for the recipe for Beef Quesadillas

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† For the purpose of this resource "fish" encompasses other seafoods, such as mussels which are a good source of iron.

Health problems, including iron deficiency, may result from an inadequate diet. They may also have a medical basis unrelated to diet. The information on this sheet is only general and is not to be taken as a substitute for medical advice in relation to specific-symptoms or health concerns.

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