Macronutrients and micronutrients are defined by the quantity in which they are needed in the diet. Macronutrients (i.e., protein, carbohydrates, and fat) are nutrients that are needed in large quantities, often in terms of tens to hundreds of grams per day. Conversely, micronutrients (i.e., vitamins and minerals) are nutrients that are needed in small quantities, often in terms if micrograms or milligrams. Similar to macronutrients, micronutrients can be found in animal and plant food sources as well as in supplementation.

Whereas macronutrients are the molecules used to produce structure metabolised directly for energy, micronutrients (both vitamins and minerals) are critical in maintaining the metabolic processes that produce energy. A good analogy for this is the different roles that petrol and oil play when producing energy in a car. Petrol is the main source of energy (the macronutrients) for the car and it is combusted (oxidised) to generate energy and make the engine run. The oil (micronutrients) is critical for allowing the engine to run smoothly, enabling all the parts to move (Figure: Understanding Micronutrients).

To be a little more specific, in the context of human nutrition and metabolism, micronutrients are used as coenzymes and cofactors for many of the metabolic reactions and are used quite extensively in the mitochondria to facilitate the electron transport chain. For example, vitamins B1 and B2 are required for the Krebs cycle to function properly, while minerals like iron and sulphur are critical in maintaining the function of the electron transport chain.

Helpful Hint

Macronutrients and micronutrients both play critical roles in metabolism, with micronutrients being crucial for facilitating energy production. A good way to think about this is that micronutrients are the oil for your car, which keeps the engine running smoothly; the macronutrients are the petrol that provide the energy.

Micronutrients are critical to maintaining robust human metabolism and overall human health. Deficiencies in micronutrients are the cause of diseases like scurvy (vitamin C deficiency), rickets (vitamin D deficiency), and blindness (vitamin A deficiency). Additionally, deficiencies in micronutrients such as magnesium can impair glucose metabolism and deficiencies in selenium can result in muscle pain and bone disorders. In developed countries, overt deficiencies in any of these micronutrients are rare; however, deficiencies still occur with alarming frequency in developed countries.

## Water-soluble vitamins

Water-soluble vitamins are defined as vitamins that can dissolve in water. Due to this ability, they are not stored in the tissue of the body but are present in the blood and other water-based fluids. Many water-soluble vitamins are essential, meaning that they must be consumed from foods or dietary supplements. They are found in both animal foods and plant foods.

Most of the water-soluble vitamins are part of the B-complex family of vitamins. Review the B-complex family in Figure: Water-Soluble Vitamins. Another water-soluble vitamin is vitamin C.

These vitamins are excreted in the urine and must be replaced daily for optimal health. Because they are not stored and easily excreted, large and/or mega doses of these vitamins are often wasteful. Much of the excess is excreted and never used by the body.

Food for Thought

Water-soluble vitamins are not stored in the tissues and excess levels are excreted. Therefore, urine becomes a vibrant, bright yellow after consumption of a large dose of vitamin B-complex vitamins, vitamin C, or a multivitamin.

### Vitamin B1 (Thiamine)

*What is it and why is it important?*

Vitamin B1, commonly referred to as thiamine, is critical in the metabolism of sugar and amino acids as well as central nervous system function. Vitamin B1 is found in high concentrations in skeletal muscle and it has been hypothesized that individuals who engage in higher levels of physical activity are more likely to have low levels of vitamin B1 and may require higher intakes of vitamin B1 or supplementation (Manore, 2000; Figure: Vitamin B1).

Deficiency in vitamin B1 can lead to several serious health conditions, specifically beriberi and Wernicke encephalopathy. Ensuring someone consumes an adequate amount of vitamin B1 in the diet can prevent these conditions. Research on the effect of vitamin B1 supplementation on performance in humans unfolds that, outside of preventing deficiencies, it does not help performance.

*Where is it found in foods?*

Vitamin B1 is found in fortified and enriched grains, as well as animal meats (beef, pork, and salmon). It can also be found in squash, black beans, and flax seeds.

*How do we apply this information?*

Most people who consume a well-rounded diet get enough vitamin B1 and, in almost all cases, supplementation is not necessary. However, if someone is eating a low-quality diet, limited in the foods shown in Water-Soluble Vitamins Handout, it would be important to have a person’s vitamin B1 levels assessed to ensure they are not deficient.

### Vitamin B2 (Riboflavin)

*What is it and why is it important?*

Vitamin B2, commonly referred to as riboflavin, is critical in the metabolism of proteins, carbohydrates, and fat and is a component of flavin adenine dinucleotide (FAD), an essential part of the antioxidant system in the body. Deficiencies in vitamin B2 result in dry skin, sore throats, and inflammation primarily due to its role in the antioxidant system. This, however, does not mean added supplementation boosts performance. The evidence on deficiencies or inadequacies in athletic populations is equivocal.

*Where is it found in foods?*

Vitamin B2 is found in a wide range of food sources: beef, fish, pork, milk, mushrooms, peanuts, avocados, and eggs. Deficiencies are not common in the normal population because of its widespread availability in the diet (refer to the Water-Soluble Vitamins Handout on the previous page (Figure: Vitamin B2).

*How do we apply this information?*

Obtaining enough vitamin B2 to maintain health is easily achieved through a balanced diet. Similar to vitamin B1, supplementation in most cases is not necessary. Furthermore, it is not something that needs to be supplemented in athletic populations unless a medical professional has assessed the diet and diagnosed a deficiency.

### Vitamin B3 (Niacin)

*What is it and why is it important?*

Vitamin B3, commonly referred to as niacin, shares many similarities with vitamin B2 because it is critical in the metabolism of proteins, carbohydrates, and fat. It is also a component of a dinucleotide, specifically, nicotinamide adenine dinucleotide (NAD). NAD plays a critical role in the Krebs cycle and electron transport chain and is responsible for much of the ATP production in our cells. Furthermore, NAD is involved in the production of many other macromolecules that are essential for optimal function, including cholesterol and fatty acids.

Though vitamin B3 deficiency is rare, occurrence leads to inflammation of the skin, headache, diarrhoea, memory loss, and, in severe cases, it can lead to death. There has been very little research conducted on vitamin B3 and physical performance. One study demonstrated that supplementation with vitamin B3 did not improve 10-mile run times in trained runners (Norris, Schade, & Eaton, 1978).

*Where is it found in foods?*

Vitamin B3 is found in many of the same foods with B1 and B2: beef, fish, pork, milk, mushrooms, peanuts, avocados, and eggs (refer back to the Water-Soluble Vitamins Handout). Given its abundance in many of the commonly consumed foods and it being included in enriched grains, deficiencies are rarely seen.

*How do we apply this information?*

Obtaining enough vitamin B3 to maintain health is easily achieved through a balanced diet and supplementation is not required for most people. Also, supplementation with vitamin B3 is not effective at improving athletic performance.

### Vitamin B5 (Pantothenic Acid)

*What is it and why is it important?*

Vitamin B5, commonly referred to as pantothenic acid, is a component to co-enzyme A (CoA). CoA serves as a molecular link between glycolysis and the Krebs cycle, which means that it is involved in the metabolism of proteins, carbohydrates, and fatty acids. Vitamin B5 also plays a fundamental role in the production of cholesterol, fatty acids, and other molecules, such as coenzyme Q10 (CoQ10).

Vitamin B5 deficiency is quite rare and occurs in cases of severe malnutrition, so it is not a primary concern for most people. Despite it being critical in one of the key molecules in all of human metabolism, there is very little research on the effect of pantothenic acid supplementation on improving overall health or improving performance.

*Where is it found in foods?*

Vitamin B5 is found in similar foods as vitamins B1, B2, and B3. Primarily, it is found in fortified and enriched grains, fish, beef, chicken, lentils, many seeds, and even shiitake mushrooms.

### Vitamin B6

*What is it and why is it important?*

Vitamin B6 represents a class of several related (but different) molecules, each of which are important for optimal health (“Office of Dietary Supplements - Dietary Supplement Fact Sheet: Vitamin B6,” 2018). Briefly, these molecules are pyridoxal, pyridoxine, and pyridoxamine. Several of these, specifically pyridoxal and pyridoxamine, play critical roles in metabolism.

These are involved in the breakdown of glycogen into glucose and the production of glucose and neurotransmitters. Vitamin B6 deficiency is uncommon in otherwise healthy people with one study showing inadequate levels of vitamin B6 being present in about 1.5% of the people studied. However, Vitamin B6 supplementation may help reduce the risk of complications in people with diabetes.

Vitamin B6 also does appear to alter fuel metabolism slightly during exercise, shifting it to use more carbohydrates and less fat. However, it does not appear to either impair or improve performance.

*Where is it found in foods?*

Vitamin B6 is found in fortified grains and in dairy along with eggs, organ meats (e.g., liver), potatoes, bananas, parsnips, and some nuts (e.g., pistachios).

*How do we apply this information?*

Consuming a balanced diet that contains animal meats and is rich in fruits, vegetables, and nuts will provide adequate vitamin B6. While most people do not require supplementation, including athletes, it may be of use for people with diabetes to reduce the risk of complications.

### Vitamin B7

*What is it and why is it important?*

Vitamin B7, commonly referred to as biotin and formerly referred to as vitamin H, is a cofactor in many carboxylase enzymes, which are responsible for transferring carbon dioxide molecules and the metabolism of carbohydrates, fatty acids, cholesterol, and amino acids..

Biotin deficiency is rare, given that it is needed in very small quantities (about 30 µg/day), is found in many common foods, and is synthesised by gut bacteria. Biotin deficiencies can result in hair loss (alopecia), dermatitis, and issues with nails. Supplementation to correct major deficiencies have shown some benefit to these conditions. However, in otherwise healthy people, biotin supplementation does not appear to provide a measurable benefit to hair, nails, or skin. While there are robust marketing claims to support biotin supplementation as a beauty aid, and one study showing a small benefit on nail health, the cumulative scientific data do not support it.

*Where is it found in foods?*

Vitamin B7 is found in similar foods as vitamin B6: organ meats, fish, nuts and seeds, and dairy. Biotin is needed in such small quantities that a diet containing dairy, nuts, and seeds usually provides enough biotin to avoid the need for supplementation.

*How do we apply this information?*

Biotin supplementation is not necessary for most people as a well-rounded, balanced diet provides enough biotin to prevent deficiencies. Furthermore, biotin supplementation does not appear to benefit hair, skin, or nails and people should not be advised to take it for this purpose.

### Vitamin B12

Vitamin B12 stands out among the B-complex vitamins in that it is the largest, comes in many forms, and contains a heavy metal/mineral in its molecular structure, specifically cobalt (“Office of Dietary Supplements - Vitamin B12,” 2018). Vitamin B12 is involved in many different metabolic processes, including DNA synthesis, red blood cell production, and in maintaining proper neurological function.

In fact, vitamin B12 deficiency can lead to anaemia, neurologic disorders, and a host of other diseases and disorders. Supplementation with vitamin B12 has been shown to improve the health of infants in developing countries, where deficiency is common (Srinivasan et al., 2017; Thomas et al., 2018). While vitamin B12 supplements are often marketed as energy supplements, there is little evidence examining the effect of vitamin B12 supplementation on athletic performance.

*Where is it found in foods?*

Vitamin B12 is found in fortified grains, shellfish, fish, beef, and dairy. Vitamin B12 is not found in as many foods as the other B vitamins; subsequently, deficiency is more common with vitamin B12 than the others. Deficiency of vitamin B12 appears to vary substantially across age groups, by geographic location, and by a country’s socio-economic status. For example, vitamin B12 deficiency in children and young adults in developed nations is between <1 to 3%, while vitamin B12 deficiency has been reported at 70 to 80% in developing countries.

*How do we apply this information?*

Of all the B vitamins, vitamin B12 needs the most consideration as deficiency is more common than the other B vitamins, especially in developing countries. Deficiency is more common in people who consume a vegetarian or vegan diet and supplementation ought to be considered among vegetarians and vegans. Furthermore, vitamin B12 status should be checked in pregnant women as vitamin B12 status may impact foetal and infant health.

### Folic acid (Folate)

*What is it and why is it important?*

Like vitamin B12, folic acid (folate) is unique among the B-vitamins; however, it plays a narrower role in human metabolism than vitamin B12. Folate helps regulate single-carbon transfers, both accepting and donating single carbons to chemical reactions. These single-carbon reactions are critical as they help produce red and white blood cells as well as DNA when cells make copies of themselves. Like vitamin B12, deficiencies in folate can lead to anaemia.

Also, similar to vitamin B12 and the other B vitamins, deficiencies in folate are uncommon in young, otherwise healthy individuals in developed countries but are higher in lower socio-economic groups and in older adults.

In pregnant women, folate supplementation may improve haemoglobin levels and reduce birth complications. Furthermore, it may also help with recovery from depressive disorders.

Folate supplementation has not been shown to improve athletic performance and the research surrounding the effect of folate on athletic performance is scarce (Matter et al., 1987). However, folate supplementation can be an important part of a nutritional strategy for certain populations, as mentioned. In fact, since folate fortification was mandated in grains in the late 90s or early 2000s, depending on the country, rates of neural tube defects have decreased dramatically and it is considered one of the most successful national health campaigns in history.

Folic Acid Fortification Levels

| **Levels of folic acid fortification in countries with mandatory fortification programs** | | |
| --- | --- | --- |
| Country | Fortification Level | Date of Implementation |
| United States | 140 µg/100g | 1998 |
| Canada | 150 µg/100g | 1998 |
| Costa Rica | 180 µg/100g | 1998 |
| Chile | 220 µg/100g | 2000 |
| South Africa | 150 µg/100g | 2003 |

*Where is it found in foods?*

Folate is found in similar foods as B12: fortified grains, seafood, lean meats and poultry, eggs, legumes (beans and peas), nuts, seeds, and soy products.

*How do we apply this information?*

Folate, like vitamin B12, deserves attention and blood levels of folate should be measured routinely in specific populations: pregnant women, people with depressive disorders, and in people with a history of anaemia. Supplementation should be considered in people with low levels of folate or in people who may consume a low folate diet (e.g., vegans or vegetarians).

### Vitamin C

*What is it and why is it important?*

Vitamin C, commonly referred to as ascorbic acid, is one of the more robust vitamins. It plays myriad roles in the human body. Deficiencies in vitamin C can lead to diseases such as scurvy as well as less-serious conditions such as dry skin.

There has been a substantial amount of research exploring the effect of vitamin C on health. Currently, the evidence indicates that adequate amounts of vitamin C is important for maintaining your antioxidant system and minimizing disease risk. However, there are not any real benefits to vitamin C supplementation, including treating the common cold among otherwise healthy people.

Vitamin C has been quite extensively studied in athletic populations and it does appear to have some benefit. Primarily, it has been shown to reduce exercise-induced muscle damage and reduce post-exercise soreness known as delayed-onset muscle soreness (DOMS). There are also some considerations for abstaining from vitamin C supplementation as antioxidant therapy may prevent adaptation to exercise. The current status of the evidence is mixed and it is not entirely certain whether vitamin C supplementation is beneficial for exercise or detrimental and in what circumstances it might play either role.

*Where is it found in foods?*

Vitamin C is found primarily in bright coloured fruit (e.g., oranges, strawberries, guavas, or cherries), capsicums, cruciferous vegetables, dark leafy greens, and tomatoes. Due to the presence of vitamin C in a wide variety of food, deficiencies in vitamin C are uncommon. However, they do still occur in roughly 7% of the U.S. population.

*How do we apply this information?*

It is important to consume adequate amounts of vitamin C to prevent diseases such as scurvy and to maintain the antioxidant system. This can be easily achieved by consuming several servings of fruits and vegetables daily. Supplementation is not necessary for most people consuming a balanced diet. Furthermore, vitamin C supplementation is not advised as an ergogenic aid. In fact, a large single serving of vitamin C can result in GI distress and sometimes lead to diarrhoea.

A diagram of a vitamin c

AI-generated content may be incorrect.

### Choline

*What is it and why is it important?*

Choline plays many important roles, but the two main roles of choline are to aid in providing structure for cell membranes and as a critical molecule for the production of the neurotransmitter acetylcholine (“Office of Dietary Supplements - Choline,” 2018). Choline also can play a role in changing how the genes are expressed by adding specific tags, methyl groups, to your DNA. This process can change whether genes are turned on or turned off. The body manufactures choline in the liver but does not make enough to cover all the choline needs of the body, meaning that choline must be consumed in the diet.

Deficiency of choline leads to organ dysfunction, primarily fatty liver and damage to muscle tissue [(Fischer et al., 2007)](https://paperpile.com/c/cZDv7y/NwwjP). Homocysteine has been hypothesised to play a role in the development of heart disease, and, as choline supplementation can lower homocysteine levels, there has been some speculation over the potential benefit of choline for reducing risk of heart disease (Olthof, Brink, Katan, & Verhoef, 2005).

Coach's Corner

It is important that people consume enough choline to prevent deficiency, but it should not be considered a supplement that prevents heart disease.

*Where is it found in foods?*

Choline is found primarily in organ meats and egg yolks. It can also be found in oysters; dark, leafy greens; cauliflower; and mushrooms.

Getting Technical

Acetylcholine is a chemical messenger that is released in muscle cells to activate muscle contraction. It is essential for all movement.

It has been hypothesised that choline supplementation might improve athletic performance by increasing how much or how long muscles can contract by increasing the amount of acetylcholine in muscle tissue. Currently, the data do not provide evidence to support the use of choline as an ergogenic aid.

*How do we apply this information?*

While choline is found in many animal and plant foods, there are some populations who are at risk for choline deficiencies, specifically vegetarians and vegans. These populations should ensure they consume choline-rich plants or consider supplementing with choline. Supplementation with choline in athletes does not appear to provide benefit and is not necessary.

Getting Technical

One double-blind study found no benefit of roughly 8.4 grams of choline citrate on a treadmill test, run time-to-exhaustion, or a squat test. A second double-blind, placebo-controlled study found no effect of 2.4 grams of choline bitrate on time to exhaustion in cyclists (Spector et al., 1995).

As a class, water-soluble vitamins are critical in the maintenance of human health. Deficiencies in these vitamins are rare and the recommended daily intake (RDI) can be achieved through a balanced diet. While deficiencies may impact athletic performance, supplementation above and beyond normal intake levels does not appear to benefit athletic performance.

In order to prevent micronutrient deficiencies for water-soluble vitamins, a person should consume a diet that includes the following:

1. Animal meats or animal by-products such as dairy or eggs
2. Green, leafy vegetables and other bright-coloured vegetables
3. A variety of nuts and seeds
4. Micronutrient-rich grains and legumes
5. Enriched or fortified grains or oils in moderate quantities

Following these basic principles can help an individual maintain adequate micronutrient status for the full spectrum of water-soluble vitamins. There are some populations that might benefit from supplementation. Vegetarians and vegans may require vitamin B12 and/or choline supplementation, depending on the makeup of their vegetarian diet.

Food for Thought

While the water-soluble class of vitamins are critical for human health, supplementation of any of them (including vitamin C) does not appear to improve performance. Furthermore, there may be some downsides to supplementing with vitamin C that need to be investigated in more detail. Most people can obtain an adequate amount of these micronutrients through a balanced diet. Individuals in lower socio-economic areas of the world, older adults, and pregnant women may require some form of supplementation or a bigger focus on ensuring they reach their daily requirements of these micronutrients. Individual needs should be discussed with a registered dietitian nutritionist or the client's own healthcare practitioner.

Critical!

If working in Australia, make sure to always refer to the [Australian Dietary Guidelines](https://fitness.org.au/articles/policies-guidelines/nutrition-advice-within-scope-of-practice-for-ausreps/4/1356/20) before educating clients on micronutrients.