

Module 3. The role of fat in a player's diet

Unit 3.1 Introduction to fat

Fat is an essential component of a footballer's diet because it has several important roles in the body. Fat is an important fuel for contracting muscle, it facilitates the absorption of fat-soluble vitamins (vitamins A, D, E and K) and provides an essential structural component of cell membranes. Although fats are important, high fat foods are also energy dense (9 kcal per gram). Therefore, players should be educated on the role of fats and the importance of ingesting appropriate quantities and sources of this nutrient. In this unit, we will provide an introduction to dietary fat, discussing fat digestion, storage, and use. This knowledge will provide context for the studies detailed in Unit 2, where the role of fat for football performance has been investigated.

DID YOU KNOW?

The terms 'fats' and 'lipids' are often used interchangeably. The key difference between lipids and fats is that lipids are a broad group of biomolecules whereas fats are a type of lipid.

Types of lipids

Lipids are defined chemically as a group of organic molecules composed of carbon, hydrogen, and oxygen that are insoluble in water. There are different types of lipids depending on their chemical structure and/or function, and can be classified into different categories (Jeukendrup & Gleeson, 2018). In general, dietary fats can be divided into three categories: saturated, monounsaturated, and polyunsaturated. The different types of fats will be discussed in more detail with the aim of understanding their relevance to the diet and to the human body, as well as the importance for football players. Most fat sources contain both saturated and unsaturated fatty acids, but in varying amounts.

Fatty acids

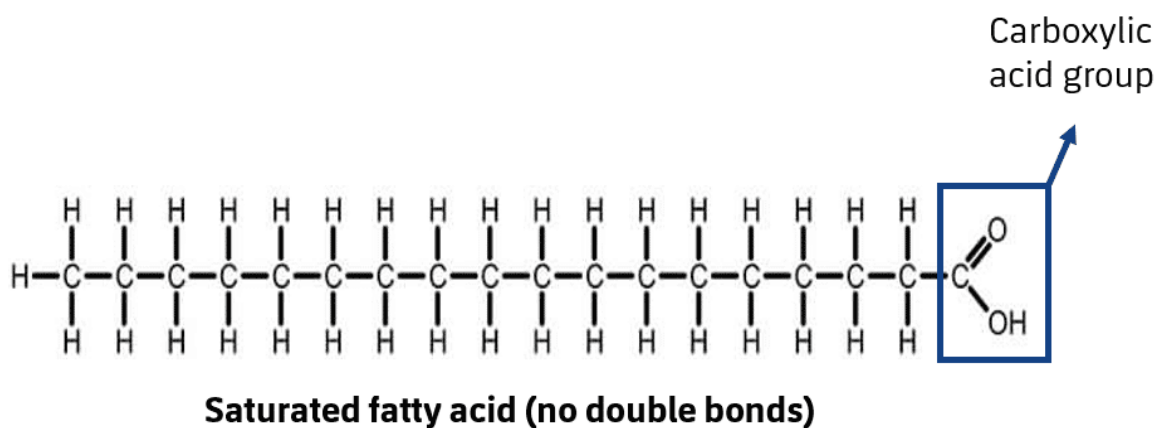
Fatty acids are composed of a chain of carbon and hydrogen atoms with a carboxylic acid group at the end of the chain. The length of the carbon chain is important, as it indicates the type of fatty acid. Typically, the length ranges from 4 to 24 carbon atoms. A fatty acid with a carbon chain of 6 or less is classified as short-chain fatty acids (SCFAs); a chain of

8-10 carbon atoms is a medium-chain fatty acid (MCFAs); and long-chain fatty acids (LCFAs) consist of >12 carbon atoms. The most abundant fatty acids are LCFAs.

Interestingly, the SCFAs (acetate propionate, and butyrate) possess regulating capacities on whole body systems including immune function (Yang & Cong, 2021), neurological processes (Morais *et al.*, 2021), and skeletal muscle metabolism (Frampton *et al.*, 2020). Of the SCFAs butyrate has been investigated the most extensively. Upon absorption, butyrate is metabolised by the intestinal epithelial cells serving as a major energy source and benefiting gut barrier integrity and function. The role of dietary fibre and the gut microbiome in enhancing SCFAs production will be discussed in course 4.

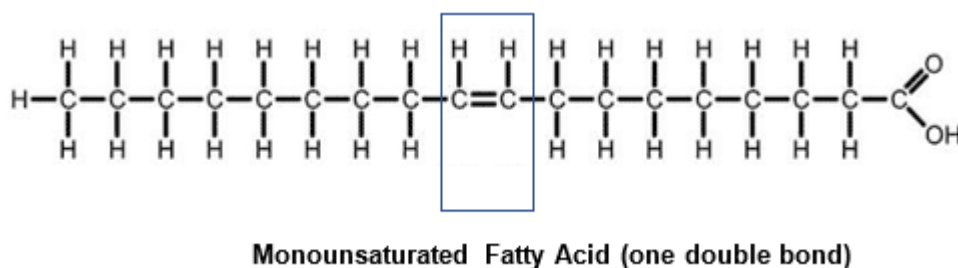
Fatty acids can also be classified according to the number of double bonds that join the carbon atoms together. A saturated fatty acid contains no double bonds. Fatty acids with one double bond are classified as monounsaturated fatty acids (MUFAs), and if two or more double bonds are present, it is called 'polyunsaturated fatty acids' (PUFAs) (see the following figures).

Figure 1: Saturated fatty acid



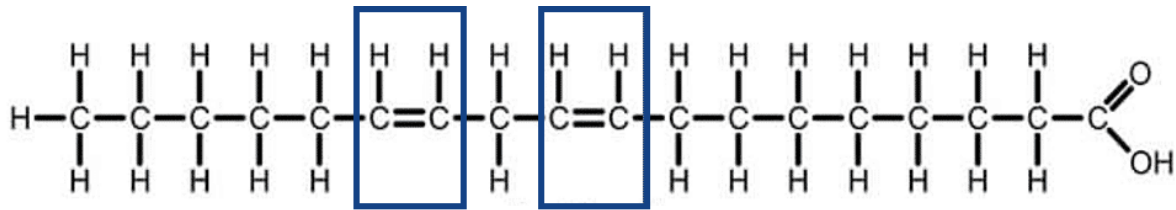
Source: prepared by the author.

Figure 2: Monosaturated fatty acid



Source: prepared by the author.

Figure 3: Polyunsaturated fatty acid



Polyunsaturated fatty acid (two double bonds)

Source: prepared by the author.

DID YOU KNOW?

Fatty acids can be classified depending on the number of carbon atoms and the absence or presence of double bonds.

Each fatty acid has a common name (table 1), but they can also be described with numbers. The numbers state the carbon atom chain length, and the number and position of double bonds. For example, the fatty acid 18:1 is oleic acid, it has an 18-carbon atom chain and 1 double bond; it is, therefore, a MUFA. This nomenclature can be extended to describe the location of the first double bond. For example, the fatty acid 18:2 (n-6) is linolenic acid, it has 18 carbon atoms and 2 double bonds; the first double bond is located at the 6th carbon atom. For your information and reference, table 1 shows an overview of some of the different fatty acids and their nomenclature.

Table 1: Different fatty acids and their nomenclature

Saturated fatty acids			
Number of carbon atoms and double bonds	Starting position of double bond	Common name	Found in
12:0	-	Lauric acid	Coconut Oil, Palm Kernel Oil
14:0	-	Myristic acid	Cow's Milk and Dairy products
16:0	-	Palmitic acid	Palm oil, meats, egg yolk
18:0	-	Stearic acid	Meat and cocoa butter
Unsaturated fatty acids			
Number of carbon atoms and double bonds	Starting position of double bond	Fatty acid name	Found in
18:2	n - 6	Linoleic acid	Olive oil
18:3	n - 3	α -Linolenic acid (ALA)	Flax seeds, walnuts
18:3	n - 6	γ -Linolenic acid	Hemp seeds, spirulina
18:4	n - 3	Stearidonic acid	Hemp seed oil
20:5	n - 3	Eicosapentaenoic acid (EPA)	Oily fish (salmon, mackerel)
22:6	n - 3	Docosahexaenoic acid (DHA)	Fish oil

Source: own source.

Some fatty acids cannot be made (synthesised) in the body, so they must be incorporated into the footballers diet. Linolenic acid and α -Linolenic acid (ALA) are known collectively as essential fatty acids and can be found in foods such as flax seeds, hemp, walnuts and spirulina. These two fatty acids are also important because linolenic acid is an omega-6 fatty acid and α -linolenic acid is an omega-3 fatty acid.

Both omega-3 and omega-6 fatty acids are important components of cell membranes. Also, omega-3 fatty acids have been found to exert many health benefits on cardiovascular disease, diabetes, cancer, depression, and various mental illnesses (Shahidi & Ambigaipalan, 2018). Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are the main long-chain omega-3 fatty acids. Both EPA and DHA can be produced in the body when ALA is included in the diet. It is also recommended for players to eat foods rich in EPA and DHA, such as oily fish, white fish, vegetable oils, nuts, soya and soya

products, and green leafy vegetables. Specific recommendations regarding omega-3 are covered in Unit 2. See table 2 for an overview of dietary sources of omega 3 and 6.

The ratio of blood lipids is considered an indicator of polyunsaturated fatty acid status. A high ratio of omega 6 to omega 3 (14:1) is unfavourable and can be an indicator of inflammation whereas higher ratios of omega 3 to 6 (2-4:1) are considered favourable and to have anti-inflammatory properties. The implications for football are discussed in Unit 2.

Table 2: Dietary sources of omega-3 and omega-6 fatty acids

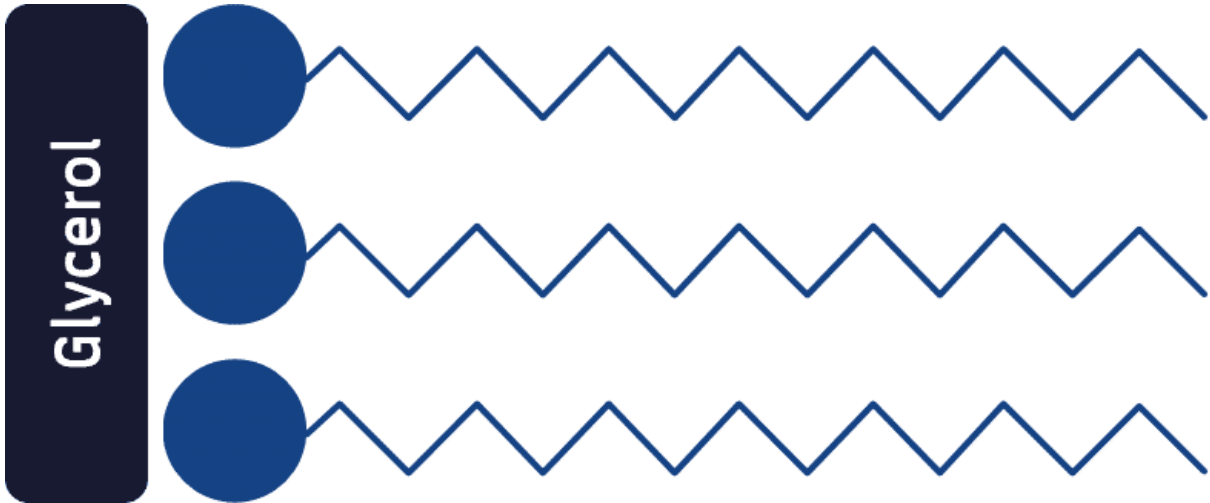
	High in Omega-3 fatty acids	High in Omega-6 fatty acids
Dietary Sources	<ul style="list-style-type: none"> • Fish (Mackerel, Salmon, Seabass, Oysters, Sardines) • Seaweed and algae • Chia seeds • Hemp seeds • Flaxseeds • Walnuts • Beans (edamame, kidney) • Green leafy vegetables 	<ul style="list-style-type: none"> • Vegetable and seed oils: corn oil, sunflower oil, grapeseed oil, cottonseed oil (and anything cooked in these oils) • Nuts: walnuts, pistachios, cashews • Sunflower seeds, pumpkin seeds • Peanut butter • Fatty meats

Source: own source.

Triglycerides

Triglycerides (TGs) are simple lipids made from the combination of a glycerol backbone plus three fatty acids. When glycerol is bound to a single fatty acid, it is called monoglyceride (MG), and when attached to two fatty acids, it is called diglyceride (DG). However, the most abundant (95%) dietary fats consumed are triglycerides; dietary MGs and DGs are also consumed, but in smaller amounts. A simplified and detailed structure of TGs can be found in figures 4 and 5; fatty acids that form TAGs can be saturated, unsaturated or a combination of both.

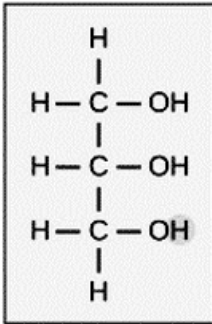
Figure 4: Cartoon triglyceride molecule



Source: own source.

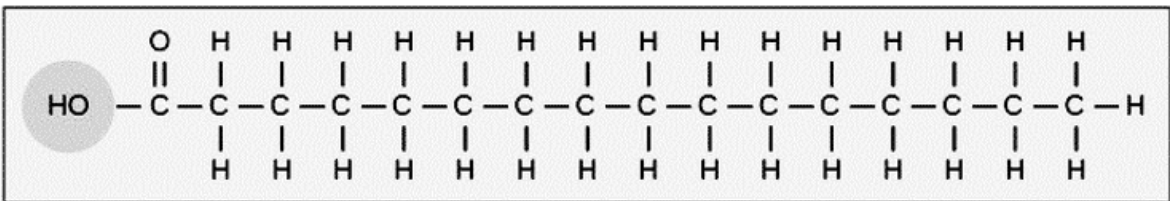
Figure 5: Formation of triglyceride

Glycerol

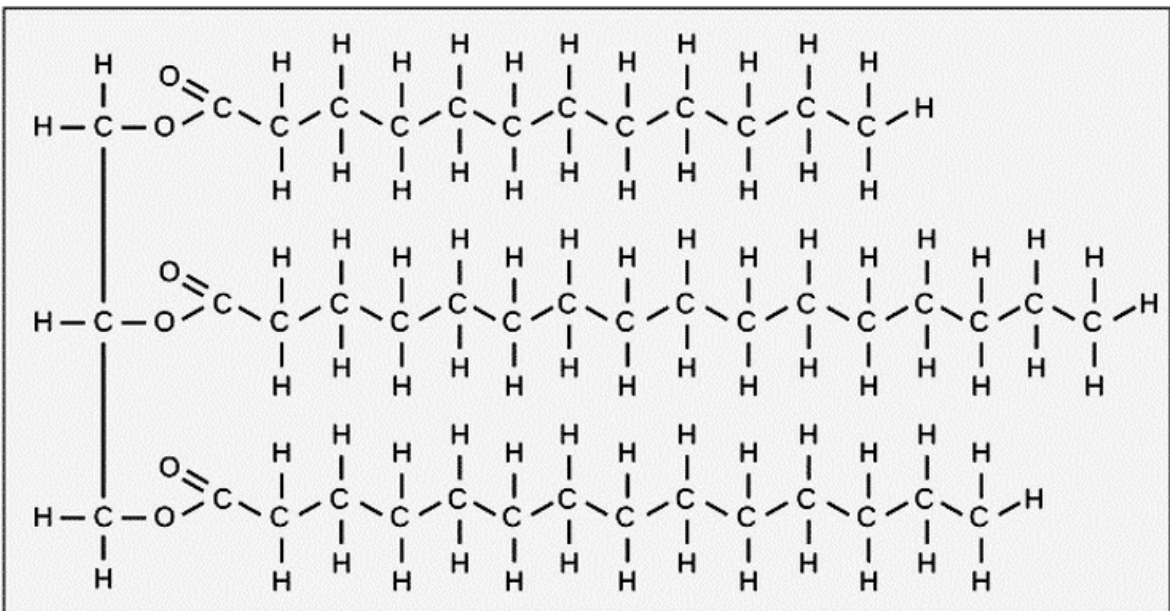


+

Fatty Acid



Triacylglycerol



Source: [untitled image of triglyceride formation], (n. d), <https://acortar.link/rxJSFR>

DID YOU KNOW?

Triglycerides are also referred to as 'triacylglycerols' and they are often abbreviated to 'TAG' or 'TGs'. For this unit, the word 'triglyceride' with the abbreviation 'TG' will be used.

Lipoproteins

Due to the insoluble nature of TGs, they need to be transported around the body by lipoproteins. Lipoproteins are made up of TGs, proteins, free cholesterol, and phospholipids (see figure 6).

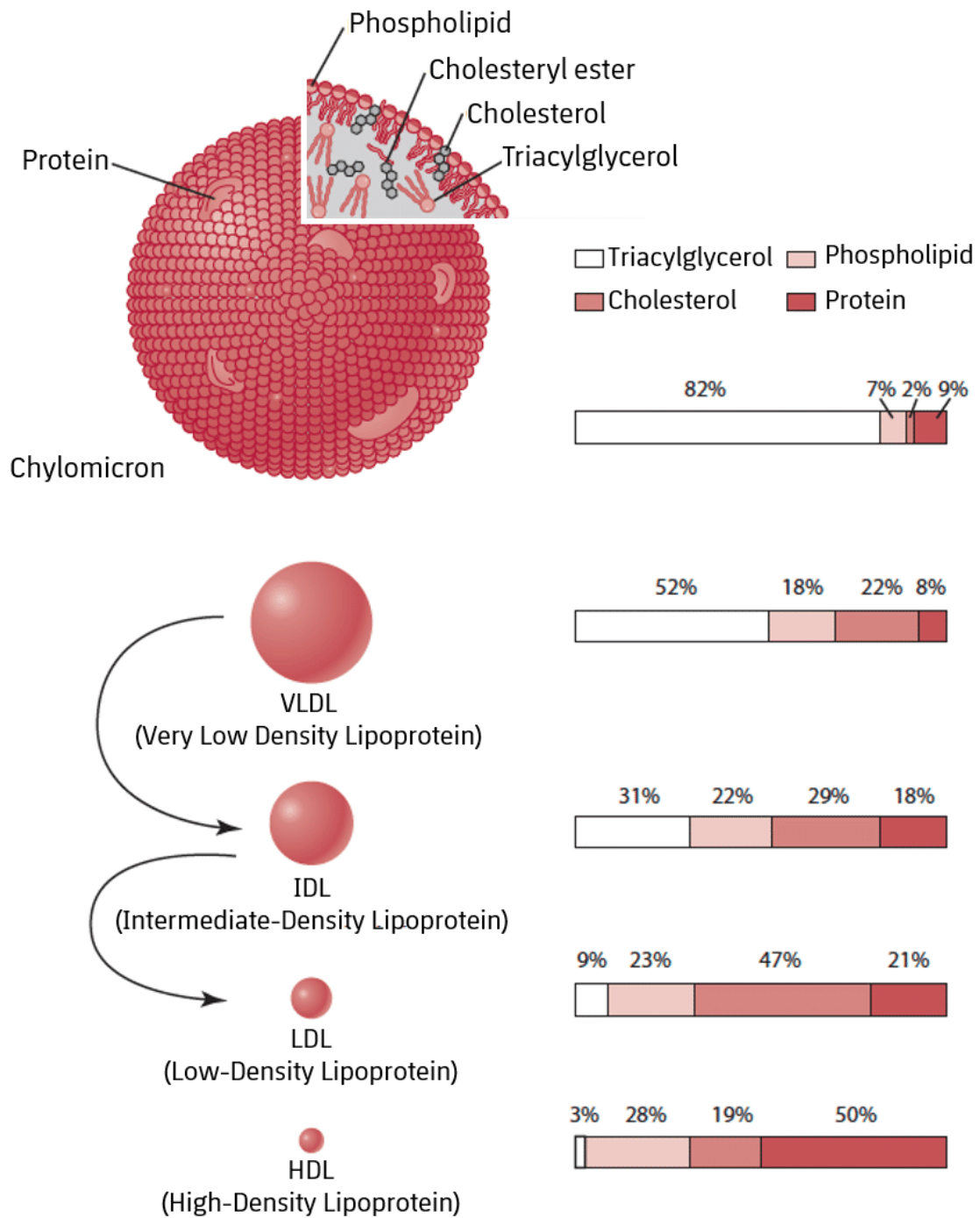
Lipoproteins have unique functions. Chylomicrons transport lipids (TGs and cholesterol) that have been eaten (exogenous) to other tissues, such as the muscle and adipose tissue, where the TGs are removed and either stored or used for fuel. The cholesterol rich remnants of the lipoproteins are transported to the liver. This process is often referred to as 'the exogenous pathway' (Walker *et al.*, 1990).

The cholesterol and TGs that reside in the liver are packaged into very low-density lipoproteins (VLDLs) and are released into the circulation. The VLDLs are transported to the adipose tissue and muscle where TGs are once again removed, leaving cholesterol-rich low-density lipoproteins (LDLs). LDLs are either taken back up into the liver or they remain in the circulation as LDL. The LDLs are commonly known as the 'bad' lipoproteins, as high levels in the circulation increase the risk of coronary heart disease (Griffin *et al.*, 1994). Since this process involves lipids that are already in the body, it is sometimes referred to as an endogenous pathway (Walker *et al.*, 1990).

High-density lipoproteins (HDLs) have a different function. They are responsible for taking cholesterol from the tissues and the circulation to the liver, where the cholesterol is removed. HDLs are known as the 'good' lipoproteins, and they have been found to reduce the risk of coronary heart disease (Gordon *et al.*, 1977).

It is common for players to routinely have blood tests which assess blood cholesterol concentrations. As a general guide, total cholesterol below 5 mmol/L is recommended. With regard to specific types, HDL concentrations higher than 1.0 mmol/L for men or above 1.2 mmol/L for women, and LDL below 4 mmol/L are general targets. Nonetheless, it is advised that the sports nutritionist works with the club doctor if any adverse blood cholesterol results are observed given the importance of diet in modifying the player's blood lipid profile (Unit 2).

Figure 6: Lipoprotein structure and content



Source: Gropper *et al.*, 2016, p. 145.

Dietary sources

The Food and Agriculture Organisation (FAO) and the World Health Organisation (WHO) suggest that daily fat intake should not exceed 30%-35% of total energy intake. Data collected from 24 European countries found total fat intake to range from 29% to 46% of total energy intake, with Portugal and Greece as the lowest and highest, respectively (Eilander *et al.*, 2015).

However, the type of dietary fat consumed is of huge importance. The FAO and the WHO recommend that saturated fatty acids should not exceed 10% of total energy intake. High levels of saturated fats are found in red meat, butter, and cheese. As mentioned above, there is convincing evidence that polyunsaturated fats decrease the risk of chronic heart disease; therefore, it is recommended that saturated fatty acids be replaced with polyunsaturated fatty acids in the player’s diet. Foods high in polyunsaturated fatty acids include nuts, oily fish, and some seeds.

Trans fats (fatty acids with a trans configuration) are not an essential part of the human diet. In fact, trans fatty acids have been found to increase LDLs and decrease HDLs, which, in turn, increases the risk of cardiovascular disease (Brouwer, *et al.*, 2010; Brouwer, *et al.*, 2013). High quantities of trans fats are often found in energy-dense, ultra-processed and fried foods. The UK Scientific Advisory Committee on Nutrition recommends that the intake of trans fat should not exceed >2% of total energy intake.

Taking this information, the sports nutritionist working in football should consider the type of dietary fats that are available to players via the menus and foods they provide. A comprehensive table of dietary fat sources can be found in table 3.

Table 3: Dietary sources of different types of fat

	Type of Fat			
	Saturated	Monounsaturated	Polyunsaturated	Trans fats
Dietary Sources	<ul style="list-style-type: none"> • Meat: fatty beef, lamb, pork • Dairy: butter, cheese, cream • Lard • Palm oil • Coconut oil • Fried food • Cakes/biscuits 	<ul style="list-style-type: none"> • Avocado • Nuts: cashews, almonds, peanuts • Cooking oils from plants or seeds: olive oil, canola oil, peanut oil, safflower oil, sesame oil. 	<ul style="list-style-type: none"> • Nuts: walnuts, pine nuts • Sunflower and pumpkin seeds • Flax seeds/oil • Fish (e.g. salmon, mackerel) • Plant-based oils: soybean, corn, sunflower oil 	<ul style="list-style-type: none"> • Baked goods: cookies, crackers, pies • Microwave popcorn • Fast-food • Frozen pizza

Source: own source.

Fat digestion and absorption

Most (~90%) dietary lipids consumed by humans are in the form of TGs; however, dietary lipids also comprise MGs, DGs, cholesterol, and phospholipids. Due to the insoluble nature of lipids, many enzymes are involved in breaking down (emulsification) lipids so that they can be digested and absorbed.

The first step starts in the mouth, where the enzyme lingual lipase works to breakdown (hydrolyse) the lipids. Once in the stomach, both lingual and gastric lipases work together to break down fatty acids. However, these enzymes only work on MCFAs and SCFAs;



therefore, a relatively small amount of digestion takes place in the stomach, because the majority of lipids consumed are LCFA. Another function of the stomach is to relax and contract, which mixes the contents to produce chyme. Thus, if a meal high in fat has been consumed, the chyme will be predominately made up of large lipids globules, containing TGs, fatty acids, cholesterol, etc.

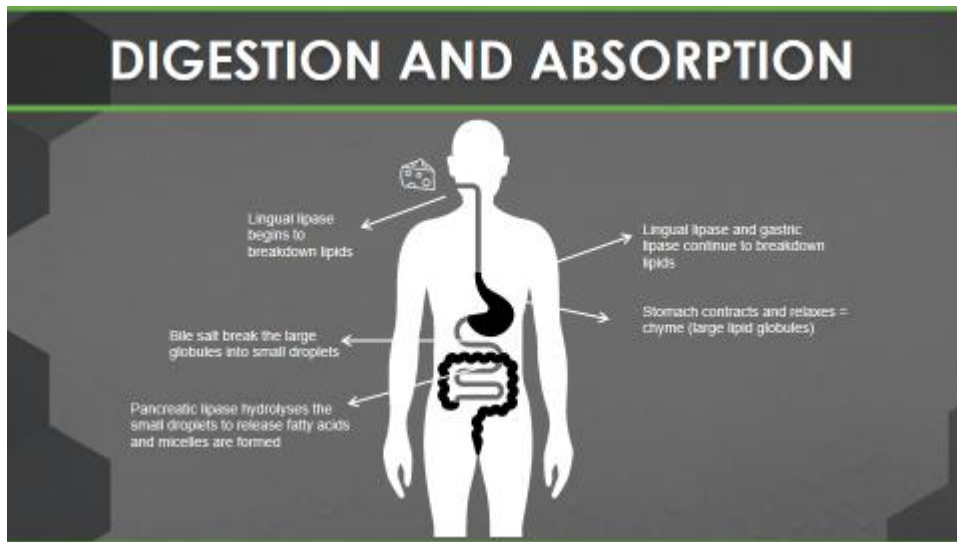
The key point here for the sports nutritionist is to understand that the greater the nutritive density of a meal is, the less volume that will be transferred to the duodenum in the 30 minutes after ingestion (Hunt & Stubbs, 1975). Thereby, ingesting high-fat meals slows the delivery of fluids and nutrients into the player's body, and should be avoided before training and matches.

These large globules of lipids are poorly absorbed by the intestines. Therefore, as the chyme enters the small intestines, bile salt (an emulsifier) is secreted to break down the globules into smaller droplets. The larger surface area of the small droplets facilitates the enzyme pancreatic lipase to further hydrolyse the lipids into fatty acids. The bile salts attach to the fatty acids and phospholipids to form micelles. These micelles are a key part of the digestion process because they are responsible for transporting the poorly soluble fatty acids to the cell membrane of the epithelial cells (the cells on the border of small intestines), where they can be absorbed. See figure 7 for a simplified overview of fat digestion.

Once at the cell membrane, the role of the micelles is complete, and the fatty acids diffuse into the epithelial cell. Inside the cell, the LCFAs are reformed (esterification) into TGs and combined with apolipoproteins, phospholipids, and cholesterol to form chylomicrons. Chylomicrons enter the lymphatic capillaries, which transport them to the venous circulation, to be taken up by various tissues. On the other hand, SCFAs and MCFAs are not re-esterified into TGs—they directly diffuse into plasma, where they bind with the protein albumin and are transported to the liver.



Figure 7: Fat digestion



Source: own source.

Storage of fat in the player's body

The major fat store in the body is subcutaneous adipose tissue, that is, a layer of fat located below the skin. Adipose tissue is an extraordinarily complex tissue, composed of distinct cell types. In players, white adipocytes (fat cells) make up the majority of the adipose tissue, which acts as the body's most important site for energy storage. However, brown and beige adipose cells are also present.

The main role of white adipocytes is to store energy in the form of TGs and to release fatty acids for fuel when needed. In contrast, brown and beige adipocytes are specialised to dissipate chemical energy in the form of heat. For a typical 80-kg male player, with a body fat percentage of 15%, ~12 kg of fat will be stored as adipose tissue. Even players with lower body fat percentages, the majority of their fat will still be stored as adipose tissue.

The TGs can also be stored inside skeletal muscle—within the muscle fibres—, and are known as 'intramuscular triglycerides' (IMTGs). However, the lipid storage capacity of skeletal muscle is much lower than that of adipose tissue. Skeletal muscle contains on average about 12 mmol/kg ww (wet weigh) IMTG (~0.3 kg of IMTG in an 80-kg male), although this can vary depending on factors such as fibre type, nutrition and physical exercise. Type I fibres contain more IMTGs than type II fibres. The IMTGs stored in muscle are an important source of energy for muscle during rest as well as in exercise conditions. Interestingly, well trained players are likely to have more IMTGs than non-trained individuals (Jeukendrup *et al.*, 1998).

Synthesis and storage process



As outlined above, after a meal has been digested, lipids are packaged into chylomicrons and are released into the circulation (exogenous pathway). Alternatively, the liver secretes lipids into the circulation in the form of VLDLs (endogenous pathway). The fatty acids in chylomicrons and VLDLs are released from their TGs by an enzyme known as 'lipoprotein lipase' (LPL). The LPL is synthesised by adipose and skeletal muscle tissue, secreted from the cell, and attaches to the endothelial lining of a nearby capillary which liberates the fatty acids (Tiidus *et al.*, 1995). Following a series of events (outlined in more detail in the lipolysis section below), the fatty acids are taken up by the tissue.

In humans, excess dietary intake of carbohydrate and fat-rich foods, over and above what is needed for fuel, leads to increased storage of fat. Most of this fat storage is a result of increased dietary fat intake, not the conversion of dietary carbohydrate into fatty acids in fat cells (Flatt 1995). In addition, high dietary carbohydrate intake will result in an increase in carbohydrate oxidation (in muscle and other tissues) and a reduction in fat oxidation. This results in more dietary fatty acids available for storage, and explains why excess dietary fatty acids are preferentially used for increased triglyceride synthesis and excess carbohydrates are preferentially oxidised. An exception is dietary fructose where excesses in the diet are primarily converted to fatty acids in the liver, promoting fat storage (Tiidus *et al.*, 1995).

Fatty acids breakdown, uptake and oxidation

Lipolysis is the process by which TGs in the muscle cells and adipose tissue are broken down to glycerol and fatty acids. Lipolysis occurs during exercise as well as in fasting conditions, when fatty acids are needed as an energy source by various tissues. On the contrary, lipolysis is suppressed within a few hours (1-2 hours) after a meal; particularly if the meal is high in carbohydrates. This process is controlled by hormones such as insulin and catecholamines.

Since triglycerides are made of three fatty acids, lipolysis requires the activation of specific enzymes to remove each of the fatty acids from the glycerol backbone. In the adipose tissue, the enzyme adipose triglyceride lipase (ATGL), hormone sensitive lipase (HSL), and monoacylglycerol lipase (MGL) remove the three fatty acids sequentially.

Once fatty acids and glycerol are released by adipose tissue as a result of lipolysis, they pass out of the adipocyte into the blood. Glycerol is soluble, but the fatty acids are bound to albumin molecules in blood. Albumin molecules are proteins which have the capacity to carry up to ten fatty acid molecules. In order to be oxidised for fuel, fatty acids must



reach the mitochondria in the skeletal muscle. To this end, the number of fatty acids delivered to muscle from adipose tissue depends on the blood flow through the adipose tissue and on the number of albumin molecules in the blood.

Once in the muscle, various transporters are responsible for the shuttling of fatty acids across the cell membrane. Fatty acid-binding protein (FABP) is located on the membrane of the muscle cell, whereas FAT/CD36 is primarily located inside the muscle and translocates to the membrane when needed. All fatty acid transporters are induced by diet and exercise. For example, endurance training will increase the amount of fatty acid transporters, potentially increasing the uptake into the muscle (Kiens, 1997). Likewise, a diet high in fat and low in carbohydrates over an extended period of time leads to a higher production of fatty acid transporters (Yeo *et al.*, 2011).

The IMTGs are another source of fatty acids that can be oxidised for fuel. Like adipose tissue, the breakdown of IMTGs is also controlled by hormones, such as insulin and catecholamines, and HSL is required to remove fatty acids from the glycerol backbone. Fatty acids in the cytoplasm of skeletal muscle, either from adipocytes or from IMTGs, must be transported into the mitochondria to be oxidised and used as fuel.

A series of processes are required to uptake fatty acids into the mitochondria. To provide a brief summary, on the outer membrane of the mitochondria, fatty acids are activated by the enzyme Acetyl-CoA synthase to form fatty acyl-CoA. Carnitine is important in transporting the activated fatty acids (fatty acyl-CoA) into the mitochondria. Carnitine is bound to the fatty acyl-CoA by the enzyme carnitine palmitoyl transferase (CPT1), forming acylcarnitine. The CPT-1 transports the acylcarnitine molecule across the mitochondrial membrane to the inner surface, whereby carnitine palmitoyl transferase 2 (CPT-2) removes the carnitine and leaves the activated fatty acid (fatty acyl-CoA) in the mitochondrial matrix. The free carnitine is translocated back to the outer membrane, where it can pick up another activated fatty acid. This is sometimes known as 'the carnitine shuttle' (see figure 8). Remarkably, only long-chain fatty acids are transported in this manner, as medium- and short-chain fatty acids are capable of passing directly through the mitochondrial membrane without a transporter. In addition, FAT/CD36 are also involved in transporting fatty acids into the mitochondria for oxidation (Lundsgaard *et al.*, 2018).

Once inside the mitochondria, free fatty acids (FFAs) enter the beta-oxidation pathway, producing acetyl-CoA and reducing equivalents (NADH, FADH₂). These reducing equivalent enter the electron transport chain, which, together with other substrates, oxygen and free adenosine diphosphate (ADP) and inorganic phosphate (Pi), generate adenosine triphosphate (ATP).



Regulation of fat use as a fuel

The increase in fat use during exercise is regulated by many of the same signals as carbohydrate metabolism. The increase in calcium concentrations at the onset of exercise activates i) key enzymes and processes involved in regulating the breakdown of IMTG (as does adrenaline), ii) the translocation of fat transport proteins at the muscle membrane; iii) the tricarboxylic acid cycle (TCA) cycle enzymes in the mitochondria (Spriet & Randell, 2020). Factors which also contribute to the regulation of fat use also include increases in free ADP and adenosine monophosphate (AMP), and activation of AMP kinase (AMPK).

As the intensity of exercise increases (~85-95% VO_2 max), fuel use shifts away from fat to carbohydrate. From a performance perspective, the fuel shift makes sense as the energy yield from carbohydrate oxidation is approximately 7% more efficient than from fat (Spriet & Randell, 2020). The mechanisms responsible for down regulating fat metabolism at high aerobic exercise intensities include a decrease in FFA release from adipose tissue, a decrease in HSL activation, and a reduction in IMTG breakdown, likely due to a small decrease in the pH of the muscle. For football, fat can be considered as the enabling fuel. This is because fat is the dominant energy source whilst the player is walking or completing low speed running (<40% VO_2 max) and provides large amounts of energy during moderate speed running (~40-65% VO_2 max). Fat oxidation also contributes energy during recovery from a single or repeated sprint completed by the player.

Summary

- Fat is an important fuel for contracting muscle and facilitates the absorption of fat-soluble vitamins (vitamins A, D, E, and K).
- Dietary fatty acids can be classified as saturated, monounsaturated, or polyunsaturated, based on the number of carbon double bonds in their structure.
- Increasing the fat content of food or meals slows the digestion and absorption of nutrients into the body.
- Adipose tissue is the main site for fat storage, providing an abundant store of energy.
- Fat is the dominant energy source during low aerobic activities, walking, low speed running, and moderate speed running.

Fat oxidation also contributes energy during the recovery periods between sprints and high intensity running.



Unit 3.2 Fats for football

Dietary fat is an important part of a player's habitual diet for the following reasons:

- 1) Fat is an energy source.
- 2) Fats are a vehicle for the intake and absorption of fat-soluble vitamins.
- 3) Dietary fat is a source of essential fatty acids.

Depending on the situation, football players are advised to adjust their intake of fat to allow protein and carbohydrate requirements to be met within total energy and sports nutrition targets (Collins *et al.*, 2021). In general, when players ingest a well-balanced diet, fat intake is likely to account for 15-20% of total dietary intake. To achieve this balanced diet, players should avoid excessive intake of saturated fats and minimise trans-fat ingestion. Therefore, common dietary modifications are to reduce the quantity of high fat foods in the players' diet and change the types of fat ingested. This is because there is emerging evidence that the ingestion of specific types of fats is of benefit to players training and recovery.

It is important to recognise that some players excessively restrict fat intake to reduce total energy intake or because they think fats are an 'unhealthy' option. An excessive restriction of fat intake to <15-20% of energy often results in an unnecessary avoidance of a range of foods with otherwise valuable nutrient profiles. Finally, players are frequently exposed to misinformation about dietary supplements for 'fat burning'; thus, this topic will also be discussed in this unit.

Fat utilisation during football

The intermittent running pattern of football allows periods of lower intensity activity. When players are stationary, walking or running at low speeds, the significant blood flow to adipose (fat stores) tissue promotes the release of FFA. Therefore, over the course of a football match, there is a gradual increase in FFA concentrations in the player's blood (Bangsbo, 1994a). The high rate of lipolysis during a game is also supported by observations of elevated concentrations of glycerol in the circulation (Bangsbo, 1994a).

In addition to an increase in blood flow to the adipose tissue, the progressive increase in FFA concentration is determined by key hormones. During training and matches, concentrations of insulin are lowered and catecholamine levels are progressively elevated, promoting a high rate of release of FFA into the blood (Bangsbo, 1994b). The FFA and glycerol concentrations during a simulated football protocol (LIST), with and without carbohydrate feedings, are displayed in figure 8. Please note that, although carbohydrate

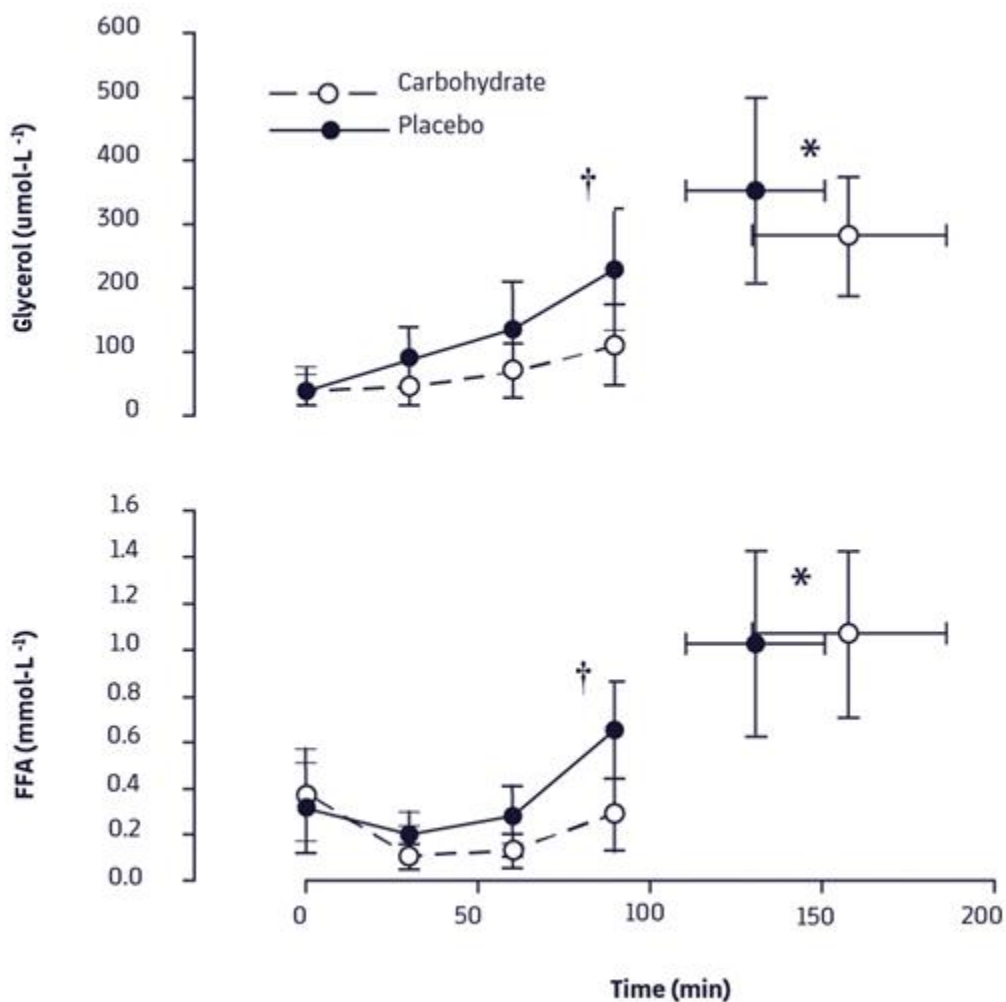


ingestion (90 g/h) reduced FFA concentrations (as expected), performance—measured via a run to fatigue—was improved with carbohydrate ingestion.

DID YOU KNOW?

‘Lipolysis’ is the term given to the breakdown of stored fat to release fatty acids.

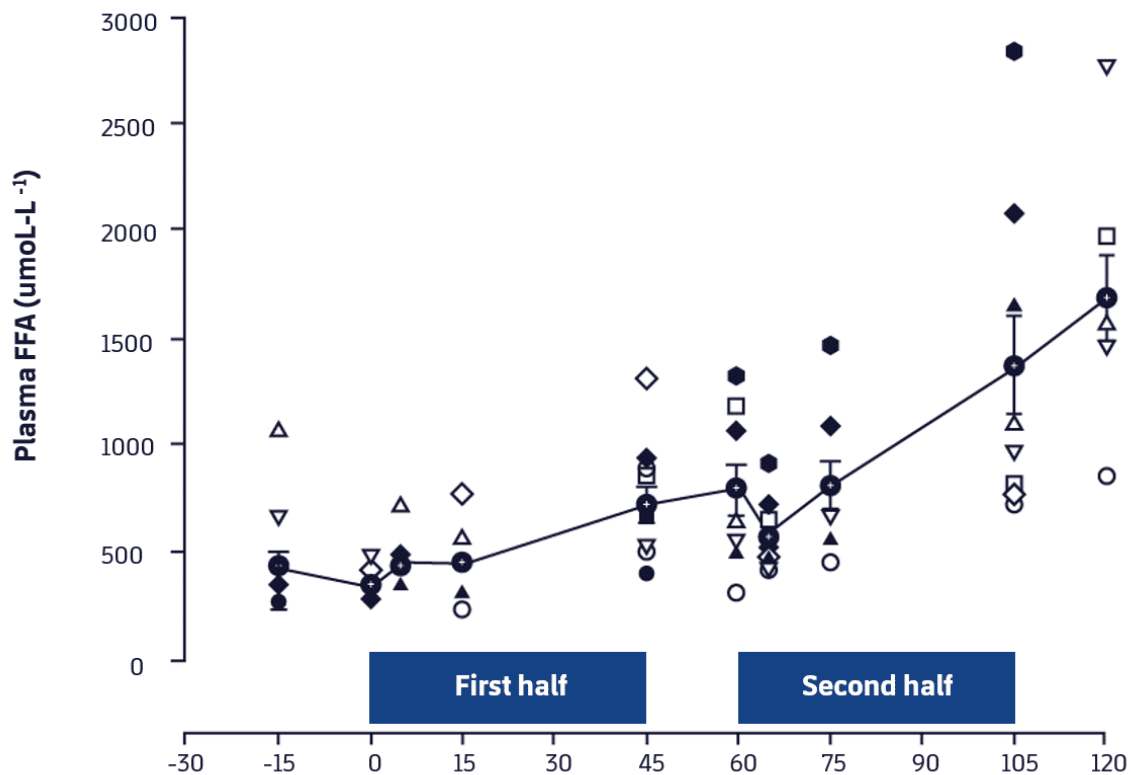
Figure 8: Free fatty acid and glycerol concentrations during the LIST protocol and at fatigue (P<0.003)



Source: Foskett *et al.*, 2008, p. 100.

Over a 90-minute match, there is an increase in FFA availability. Increasing fat use is likely a compensatory mechanism for the progressive lowering of muscle glycogen. Interestingly, in the first 20 minutes, a slight reduction in FFA in the circulation is observed. The reduction in FFA concentration following kick-off in the first and second half of a game (see figure 9) reflects higher uptake and use of FFA by contracting muscles.

Figure 9: Plasma FFA concentrations before, during, and after a football match. Data are means as well as individual values



Source: Krstrup *et al.*, 2006, p. 1169.

Fat oxidation in football

Exercise intensity is the most important factor influencing fat utilisation. At higher exercise intensities, fat use declines—despite increased energy requirements—and carbohydrate becomes the predominant fuel source. A single incremental exercise test (FATMAX test) can establish an individual player’s fat oxidation rates over a wide range of exercise intensities and establish maximal fat oxidation (MFO) rates. This test can also establish the exercise intensity at which the rate of fat oxidation is greatest (FATMAX). The player’s FATMAX is expressed as a percentage of their maximal oxygen uptake or a percentage of maximal heart rate.

Team sport athletes who participate in rugby, American football, basketball, and football display higher absolute MFO rates compared to sports such as golf, baseball and tennis (Randell *et al.*, 2017). Importantly, studies utilising the FATMAX test have consistently reported significant individual variation in maximal rates of fat oxidation within each sporting sub-group. In football, fat oxidation rates ranged from 0.17 to 1.11 g/min in a



group of 283 players that included recreational as well as professional athletes (Randell *et al.*, 2017).

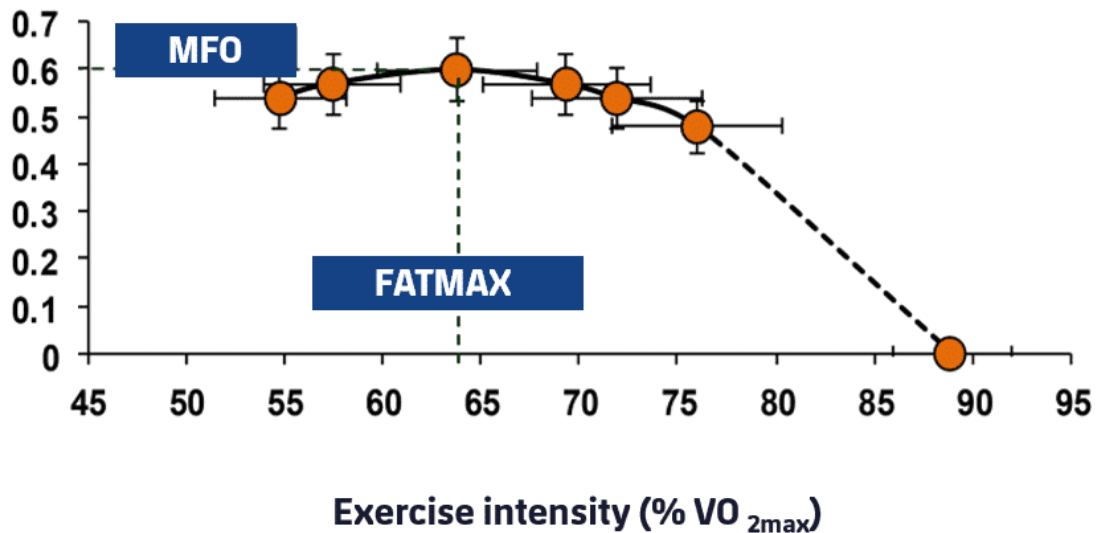
We successfully integrated FATMAX tests into pre-season medical testing at FC Barcelona (Randell *et al.*, 2019). Players routinely complete a cardiac screening test on a treadmill. We simply adjusted the exercise protocol and collected expired air. This approach allowed unique insights into professional players' metabolism, without any additional burden on their time. On two occasions, separated by a year, sixteen first team male professional football players completed a graded exercise test in a fasted state (\rightarrow 5 h). Rates of fat oxidation were determined using indirect calorimetry. Furthermore, the shape of the fat oxidation curves was modelled on an individual basis. We found that, although average absolute maximal fat oxidation rates were 0.69 ± 0.15 g/min, there was a wide range in maximal fat oxidation (0.45-0.99 g/min), as well as the exercise intensity that FATMAX occurred. These values show that professional football players have a high capacity to oxidise fat. Interestingly, we also found that individual player fat oxidation curves were similar when tested 1 year apart (Randell *et al.*, 2019).

Fat oxidation during a match and/or training is of interest, as higher rates of fat oxidation during periods of lower-intensity exercise may potentially preserve the bodies' limited supply of muscle glycogen (module 1). The available literature would suggest that individual players will have significantly different capacities to use fat. Thus, understanding an individual player's fuel preference (carbohydrate or fat) at lower exercise intensities may allow more personalised nutrition recommendations for training and matches. However, further research is required before solid nutritional recommendations based on this information can be made for players. Nonetheless, the FATMAX test also serves as an excellent educational tool to show the importance of carbohydrate metabolism at high exercise intensities.

Interestingly, significant and positive associations have been reported between maximal rates of fat use during exercise and total fat use measured over 24 hours (Robinson *et al.*, 2015). Future research may provide more insight into the long-term implication of this relationship, which could be a first step towards specific 'fat'-orientated nutrition strategies for players. The relationship between exercise intensity and fat use during exercise can be seen in figure 10. The FATMAX test can be performed on a treadmill or cycle ergometer.

Figure 10: MFO and intensity at which MFO is achieved (FATMAX)

Fat oxidation (g/min)



Source: own source.

FAT IN RECOVERY

Little research has been completed to understand the importance of fat as a fuel in skeletal muscle during recovery from prolonged high intensity intermittent exercise. Nonetheless, fat oxidation is elevated after exercise when compared to a resting control situation (Henderson *et al.*, 2007). Maletesta *et al.* (2009) compared fat oxidation during 3 hours of recovery in response to three different exercise conditions. 1) 60 minutes of continuous exercise at 45% VO_{2max}; 2) high-intensity intermittent exercise (1 min at 80% VO_{2max} with 1 minute of active recovery at 40% VO_{2max}), repeated/adjusted for each subject to match the mechanical work output to that completed during the continuous exercise; 3) time-matched resting control trial. Interestingly, the increase in total fat oxidation following the two iso-energetic exercise trials were the same in the recovery period and higher than the control trial. This occurred despite less fat oxidation during the higher intermittent exercise trial compared to the continuous exercise trial. Therefore, the results of this study suggest that the total energy expended during exercise governs the rate of fat oxidation during the 3-hour recovery period (Malatesta *et al.*, 2009). Although more research is required to examine fuel utilization during recovery from football-specific exercise, fat ingestion is not a recovery priority.

High fat diets

There has been interest in chronic adaptation to a ketogenic low-CHO, high-fat (LCHF) diet, to increase the capacity for fat utilisation during exercise (Volek *et al.*, 2015). The

challenge in football is that you may encounter anecdotal reports that some professional football players or teams follow a low-carbohydrate high fat diet.

To date, the use of low-carbohydrate diets in football has been limited to body composition management. When players restricted their carbohydrate intake to less than 30 grams a day for 30 days, a higher decrease in body fat percentage was recorded in comparison to a western diet. Reductions in body fat were achieved without compromising repeated sprint or jump performance (Paoli *et al.*, 2021). Nonetheless, beyond body composition, no observational or clinical research studies involving football and low-carbohydrate diets have been completed. This is most likely due to the lack of rationale for completing such studies.

The concept for high-fat diets is that players can increase the utilisation of the abundant endogenous fat stores (>30,000 kcal), and, therefore, they 'spare' the limited storage of carbohydrate sources (~2,000 kcal). As mentioned, despite anecdotal reports, there is no intervention research which would promote a low-carbohydrate, high-fat diet for football specific (repeated sprint) performance (Burke, 2015). However, the effects of a high-fat diet versus a carbohydrate-rich diet while training have been investigated in endurance athletes. In this study, five days of high-fat intake (4.6 g/day) were followed by 1 day of a carbohydrate-rich diet (restoration: 10 g/kg) and rest (Stellingwerff *et al.*, 2006). This study measured the regulation of key regulatory enzymes in the pathways of skeletal muscle fat and carbohydrate metabolism during sprint exercise (Stellingwerff *et al.*, 2006). Resting pyruvate dehydrogenase activity was lower at rest, and estimated rates of glycogenolysis were reduced upon the completion of a standardised 1-min. sprint after fat adaptation compared with a high-carbohydrate diet. The results from this study suggest that muscle glycogen 'sparing', as a result of increased fat use, may be due to an impairment of glycogenolysis (due to a down regulation of pyruvate dehydrogenase). Thus, high-fat diets which promote such adaptation would not be considered as favourable to players who are required to perform repeated bouts of maximal sprint activity. Finally, although endurance trained muscle can use large amounts of fat at relatively high exercise intensities (up to 75% VO_2max , when carbohydrate availability is limited), this is associated with an increased-oxygen cost. This reduction in exercise economy may partially explain impaired performance at higher exercise intensities (Burke *et al.*, 2017). Thus, due to a lack of evidence, the UEFA consensus statement for nutrition for elite football players concludes a low-carbohydrate, high-fat diet is not recommended for footballers.

DID YOU KNOW?



Pyruvate dehydrogenase is a key enzyme required to turn the products of carbohydrate metabolism (glycolysis) into acetyl-CoA, which can then proceed to aerobic metabolism.

Whole foods

It is common for sports nutrition studies to investigate macronutrients in isolation. For example, in protein research, protein isolates (such as whey or casein) have been commonly investigated, rather than the 'whole food', in this case, milk. Real foods contain a complex matrix of vitamins, minerals, and other macronutrients, including fats. Thus, investigations into 'whole foods' are more representative of a player's diet.

The first study to investigate whole foods in the context of recovery was performed by Elliot *et al.* (2006). In this study, participants ingested one of three milk drinks 1 hour after resistance exercise. The three drinks were all milk, but differed in their fat content. One drink was fat-free milk, the second drink was whole milk and the third drink was fat-free milk but with added sugar so that it had the same energy content as the whole milk. It was found that the availability of amino acids for protein synthesis was higher following the ingestion of whole milk in comparison to the other drinks (Elliot *et al.*, 2006).

Similarly, the ingestion of whole eggs immediately after resistance exercise has been reported to result in greater stimulation of myofibrillar protein synthesis than did the ingestion of egg whites, despite being matched for protein content (van Vliet *et al.*, 2017). Thus, there is emerging evidence the ingestion of nutrient- and protein-dense foods differentially stimulates muscle anabolism compared with protein-dense foods alone. Further research is required to fully understand this interaction and response. Nevertheless, with respect to module 2 (protein), the inclusion of 'non-protein' dietary factors, such as fats, may be important to influence the post-exercise adaptive response and recovery of the player's muscle (Abou Sawan *et al.*, 2018). These findings highlight the need to provide 'food' options in the recovery occasion and not to rely solely on the use of sports nutrition products.

Fat burners

A common category of nutrition supplements promoted in the media and on-line, and which the player is frequently exposed to, are 'fat burners.' The term 'fat burner' is used to describe nutrition supplements that are claimed to acutely increase fat metabolism or energy expenditure, impair fat absorption, increase weight loss, increase fat oxidation during exercise, or somehow cause long-term adaptations that promote fat metabolism (Jeukendrup & Randell, 2011). This category of supplementation often appeals to the



players as a quick fix for improved health and performance. Advertisements are often accompanied by 'aesthetically' driven marketing, with 'claims' such as improvements in performance, weight loss, fat loss, muscle gain, or a combination of these factors.

A full module will be dedicated to dietary supplementation in football in later courses. Ingredients which have been proposed to increase fat burning are listed in figure 11. It is important to note that dietary supplements often contain several of these ingredients, each with a different proposed mechanism of action. It is often claimed that the combination of a number of these substances will have additive effects. However, very few dietary supplements have appropriate evidence to support their use. The expansive list of fat-burning supplements is industry (profit) driven and it is likely to grow at a rate that cannot be matched by a similar increase in scientific underpinning. Thus, for most supplements claimed to be 'fat burners', there is a lack of scientific data. Based on my experience, caffeine, green tea, and blackcurrant are common nutrition strategies to enhance fat metabolism; therefore, they are discussed below.

Figure 11: A list of available supplements that have been proposed to increase fat metabolism

<i>Caffeine</i>	<i>Lipase</i>
<i>Dihydroxyacetone</i>	<i>Forskolin</i>
<i>Conjugated linoleic acid (CLA)</i>	<i>Lecithin</i>
<i>Carnitine</i>	<i>Ma huang</i>
<i>Ephedra</i>	<i>Beta-sitosterol</i>
<i>Psyllium</i>	<i>Fucoxanthin</i>
<i>Calcium</i>	<i>Kelp</i>
<i>Green tea extracts</i>	<i>Cayenne pepper (Capsaicin)</i>
<i>Pyruvate</i>	<i>Garcinia</i>
<i>Choline</i>	<i>Cambogia</i>
<i>Hydroxycitrate (HCA)</i>	<i>Inositol</i>
<i>Leucine</i>	<i>Taurine</i>
<i>Chromium</i>	<i>Tea</i>

Source: adapted from Jeukendrup & Randell, 2011.

Caffeine

Caffeine ingestion may increase energy expenditure (at rest) or fat oxidation (at rest and during low-intensity exercise), but these effects are less obvious during moderate- to high-intensity exercise. It is important to note that caffeine on its own has not been shown

to be effective in reducing body weight (Jeukendrup & Randell, 2011). Caffeine ingestion at high doses (~5-9 mg/kg/body mass ([bm])) has been found to increase resting FFA and glycerol concentrations, but many studies have not reported corresponding increases in fat oxidation rates (Graham *et al.*, 2000). Therefore, the common consensus is that caffeine may exert a small effect on increasing fat metabolism, but studies should be interpreted with caution. The high doses of caffeine used in experimental studies are not advised for football players, due to the potential to impact sleep and gastrointestinal comfort. Therefore, ingestion of caffeine for performance purposes should be the focus not in pursuit of fat burning.

Green tea

Green tea or green tea extract, due to the large polyphenol content, has been studied extensively due to its potential ability to increase thermogenesis and fat metabolism (Hodgson *et al.*, 2013). Research has not found green tea supplementation to influence fat use during exercise (Randell *et al.*, 2013). Green tea ingestion may have the potential to increase fat metabolism at rest, although the data is limited (Randell & Spriet, 2020). Therefore, any practical recommendations with regard to green tea ingestion to promote fat burning for players is not clear.

Blackcurrant

Blackcurrant has been reported to increase peripheral blood flow (Matsumoto *et al.*, 2005). Increasing blood flow to the adipose tissues may theoretically increase the delivery of fat as a substrate to the contracting muscles for oxidation. Seven days of supplementation with 300 mg/d of New Zealand blackcurrants in male participants resulted in a significant increase (27%) in fat oxidation during moderate intensity exercise (65% $\dot{V}O_2$ max) (Cook *et al.*, 2015). A similar increase in fat oxidation was also reported in females albeit when a higher dose (600 mg/d) of New Zealand blackcurrant was consumed for a week (Strauss *et al.*, 2018). Indeed, improvements in fat oxidation are associated with higher dose trials (600 and 900 mg/d, respectively) (Cook *et al.*, 2019). Although further research is required, the ingestion of New Zealand blackcurrant (300 mg/day) may be considered as a dietary intervention for players. This recommendation is provided in context of the other reported potential benefits to football performance (Perkins *et al.*, 2015; Willems *et al.*, 2016).

NUTRITIONAL TRAINING STRATEGIES

Of note is that the impact of caffeine, green tea, and blackcurrant on fat metabolism is minor in comparison to those factors (i.e., training status, exercise intensity, exercise duration, carbohydrate status) known to influence fat metabolism at rest and during

exercise. Ingesting carbohydrate prior to exercise has been found to decrease fat oxidation rates during continuous exercise by approximately 30%. Conversely, completing training with low muscle and/or liver glycogen availability has been found to increase fat oxidation as well as the expression of genes involved in fat metabolism. Therefore, it is important as a nutritionist in football to understand how nutrition can complement training strategies to promote fat oxidation.

Fasted training

Fasted training refers to training in the morning following an overnight fast, with no food ingested prior to or during exercise. This training protocol has been associated with an increased oxidative capacity of the muscle (De Brock *et al.*, 2008). During this training, muscle glycogen concentrations may be normal, but liver glycogen is low. This intervention may be considered a targeted time of the season, or light training or recovery days during the microcycle.

Training twice a day

Although this is not common during the season, it is common for players to train twice a day during pre-season. Training twice a day could also be introduced for players physique management. This method manipulates fuel availability, as the second training is performed with low muscle glycogen availability, by restricting carbohydrate intake following the first session. However, it should be highlighted that this method typically reduces the exercise intensity at which the second exercise bout can be performed. Thus, this type of training regime is recommended to be implemented at specific times of the season, or for individual players when performance is not the primary goal.

Train high, sleep low

The premise of the 'train high, sleep low' strategy is that the restriction of carbohydrate following training in the evening prolongs the duration of low carbohydrate availability. The consequence is that the course of metabolic gene expression for fat oxidation will be extended and possibly augmented. This may be considered for players in physique management; however, it would be discouraged during the season or during periods of fixture congestion where the opportunity for overnight recovery should be maximised.

OMEGA-3

Players should avoid unfavourable lipid profiles (pro-inflammatory) to prevent excess trans-fat, saturated fat, and excessive omega-6 fat, from vegetable oils, in the diet. Instead, players are encouraged to regularly eat foods rich in omega-3 (Simopoulos, 2007). Omega-3 has known health benefits and comes in three different forms, as explained below.



Alpha-linolenic acid (ALA) cannot be synthesised by the player’s body, so it must be obtained by ingestion in the player’s diet. The ALA is required to make other omega-3 fats. Dietary sources of ALA include vegetable oils, green leafy vegetables, rapeseed (flaxseed), and nuts (walnuts and pecans). The ALA is used to synthesise eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (unit 1). It is these fats which are associated with health benefits such as lower risk of heart disease (Mori, 2017).

The best way of ensuring players ingest enough EPA and DHA is to recommend for them to eat foods rich in these fats. Fish, and especially oily fish, are good sources of EPA and DHA. Oily fish, such as salmon and mackerel, have the highest levels of omega-3. White fish also contains omega-3 but at lower levels than oily fish. There are no specific daily recommendations for omega-3 intake, but as a guide, players are encouraged to ingest sources (see table 4) of omega-3 in their diet 2-3 times per week (Mori, 2017).

Table 4: Examples of food sources of omega-3 rich foods and good options of fat sources for the player’s diet

Fish (omega-3)	Non-fish alternatives	Other
Mackerel, tuna, cod, haddock, plaice, pollack, salmon	Soya and soya products, green leafy vegetables, nuts and seeds, vegetable oils	Avocados, cheese, eggs, olives (oil)

Source: own source.

The daily ingestion of 4-5 grams of omega-3 fatty acids may positively impact post-exercise inflammation and enhance muscle adaptive responses to exercise (Philpott *et al.*, 2019). Despite dietary advice, it is difficult for players to ingest sufficient quantities of food to get the dose of omega-3 associated with benefits. Therefore, additional nutritional strategies for players to achieve the optimal fatty acid status throughout the season are of interest.

In research studies, omega-3 has been provided in capsule form rather than food. This method allows better control on the quantity of omega-3 provided, whereas levels are likely to vary in food. These studies have found dietary supplementation of 4-5 grams of fish oil per day to improve muscle sensitivity to anabolic stimuli, resistance exercise, and protein ingestion. Thus, the ingestion of omega-3, in combination with the ingestion of protein, may be an effective strategy in maintaining muscle mass or promoting



adaptation (recovery) (McGlory *et al.*, 2016; Smith *et al.*, 2011). The ingestion of omega-3 fatty acids may also be an important consideration for the injured player in the return to play process, which will be discussed in later courses.

The ingestion of EPA may also be considered following matches, especially during periods of fixture congestion, to reduce symptoms of eccentric exercise-induced muscle damage, due to the physical demands of match-play. Research has found that acute intake of a fish oil capsule high in EPA (EPA: 750 mg; DHA: 50 mg), immediately after muscle damaging exercise, improves functional performance and perception of soreness in the days following exercise (Jakeman *et al.*, 2017; Tartibian *et al.*, 2009). In a study specifically performed in football players, the influence of adding omega-3 (EPA: 550 mg; DHA: 550 mg) to a whey protein and carbohydrate containing beverage was investigated following eccentric (muscle damaging) exercise. The beverage composition of carbohydrate and protein was similar to that typically ingested by football players following training and matches. The player ingested the beverage either with or without the additional omega-3 for a 6-week period prior to the exercise test (Philpott *et al.*, 2017). Although no differences in muscle function or football performance were observed between groups, the addition of the fish oil did improve perception of muscle soreness (Philpott *et al.*, 2017).

As a sports nutritionist, you should recognise the importance of perceptual or subjective responses of your players. Even though a sports nutrition strategy may not directly benefit performance outcomes, if a player is 'feeling better' following a nutritional intervention, it is worthwhile. Working closely to monitor physical and perceptual responses following a sports nutrition intervention is therefore advised.

Summary

- Fat is an important component of the player's overall energy intake.
- Individual players will vary significantly on their capacity to use fat as a fuel during exercise.
- Players are advised against the use of 'fat burning' dietary supplements.
- Players are recommended to ingest meals rich in omega-3 twice a week.
- Daily intake of 4-5 g of omega-3 may improve the player's recovery following muscle damaging exercise, as well as their perception of muscle soreness.

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[untitled image of triglyceride formation], (n. d), <https://bit.ly/2Dnvk6C>

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