Chapter 3. Fats & Lipids

3.1 Fat Needs and Restrictions

Fats and lipids provide the densest source of energy substrate and the functional materials for cell walls and other molecular structures. Fats and lipids in the body are obtained from dietary sources as well as made in the body endogenously. Since the body is able to synthesize fats and lipids when necessary to sustain physiologic functioning, no daily RDA or AI level for total dietary fat has been determined. There is, however, a 20–35% AMDR for total fat included in the DRI. Currently, statistics show that dietary fat accounts for 33% of total energy calories consumed by the average American.

Nutrition researchers continue to strive for a better understanding of the many variations of fats and lipids in foods. Identifying optimum total fat in the overall diet is no longer toward the standard as researchers refine their focus on fat subtypes, their sources and the role of fat physio-chemistry in human health. This more sophisticated understating of fats and lipids in foods is reflected in the newest iteration of the NFP that lists only calories without the percent that are derived from fat.

Figure 3.1 Nutrition Facts Panel

Major research concentrations today examine the optimal levels of essential and liquid fats and, with increasing momentum, more specific solid fat restrictions that mitigate the onset of chronic cardio-metabolic diseases and early morbidity. Efforts to teach the public how to distinguish between liquid and solid fat types have recently taken the form of a variety of “good fat” and “bad fat” foods promotional campaigns. Despite efforts to increase liquid oil intake, solid fat intake remains a more significant source of total fat calories in the American diet as adults consume near two times more solid fat than liquid fat daily

While several physiological vital lipids must be synthesized by the human body only two of them must be consumed in the diet. The RDA for **essential fats**, linoleic acid (LA) and alpha-linolenic acid (ALA) has been established for men and women in an approximately one-to-six ratio, respectively. Adults in the US meet the adequate intake for LA and ALA with daily average intakes of 17.2 and 1.8 grams per day, respectively. Americans, however, do not meet WHO guidelines for pre-formed fats, found only in a small number of animal foods. Since pre-formed fats are endogenously made, there is no DRI; however, since there seems to be a limitation in the conversion of essential fatty acids LA and ALA to longer chain fats needed in the body, the WHO developed an additional guideline for combined DHA and EPA to aim for .3-.5 grams per day. The longer chain fatty acids EPA and DHA are said to be “conditionally essential” and it is recommended to consume direct sources of these particular long chain fatty acids.

Table 3.1. Summary of Daily Fat Intake Guidelines

While the IOM hasn't yet determined an upper limit for the two major solid fat types or cholesterol, within the RDA it is suggested that **saturated** and **trans fat,** as well as **cholesterol**, intake should be minimized "as much as possible" while consuming a nutritionally adequate diet. A UL for saturated and trans fat, and cholesterol is not determined, as incremental increases in daily intake is associated with increasing dyslipidemia and risk for cardio-metabolic diseases. Saturated fat restrictions specifically, remain a target in of nutrition research and a focus in the 2015 Dietary Guidelines, which promote that no more than 10% of calories should come from saturated fat. The latest iteration of the Dietary Guidelines de-emphasized cholesterol restrictions compared to the 2005 and 2010 iterations, which more heavily promoted restricting cholesterol to 300 mg per day or less. Americans are within the cholesterol intake guidelines, consuming on average approximately 270 mg per day.

3.1 Homework 1

Homework • Unanswered

What is the approximate range in daily fat intake (in grams) that corresponds to a 20-35% fat, 2000 calorie diet ?

- ○ **A** 10-25
- ○ **B** 20-55
- ◉ **C** 45-75
- ○ **D** 125-200

Explanation

2000 x 20% = 400 calories from fat. Every 1 grams of fat = 9 calories, so 400/9 = 44 grams
2000 x 35% = 700 calories from fat. Every 1 gram of fat = 9 calories, so 700/9 = 78 grams

Answered - Correct!

1 attempt left Retry

3.1 Homework 2

Homework • Unanswered

Review the compositional data for flaxseed oil (image). Does the alpha-linoleic acid in a one TBSP (15 grams) serving meet the .6-1.2% AMDR in a 2000 calorie diet?

- A yes
- B no

Explanation

just one 15 grams of flax seed oil provides 8 grams of n-3 alpha linoleic acid. 8 x 9 = 72/2000 = 3%.

Answered - Correct! 1 attempt left Retry

3.2 Fat Sources

Fats and lipids are provided in the human diet mainly in animal foods and, to a lesser extent, foods of plant origin. The physiochemical manifestations of fat stored in plants and animals generally differs. Plants typically contain a higher proportion of fats that have lower melting points, are more susceptible to chemical reactions, and are in liquid state at room temperature. Animal foods are typically higher in fats that are compact and solid until heated, and less participative in chemical reactions. There are a few natural exceptions to the fat type-species classification system, the most relevant to human diet being liquid fat-rich fish, and solid fat-rich tropical nuts and seeds, mainly coconut, palm kernel and cocoa beans. Besides those dietary exceptions and common misconceptions that exist because of certain seemingly defiant foods such as solid avocado meat, rich in liquid fat, or liquid milk, rich in solid fats, the rules for characterizing fat by solid and liquid forms by species are sound.

Solid fat from animal meats consumed separately and as a part of mixed meals constitutes approximately 25 to 30% of the total solid fat intake in the US. Animal meat portions vary in their total fat content by species, body part, age, diet and activity levels, and they're cooking and processing methods. Solid fats stored intramuscularly and subcutaneously are included in commercial cuts of meat. Extracellularly stored solid fat like “trimmings,” or fat marbleized muscle fibers, can be rendered by heating and used for a variety of cooking applications. Intracellularly stored fat is more often consumed directly in the meat unless the cell wall is broken by cutting or slicing. The most common animal sources of solid fat in the US are beef, pork, and poultry. Less common sources include lamb, shellfish, and non-bird game animals. Both men and women in the US consume more than ideal amounts of animal foods, with men surpassing the 26 ounces per week guideline by more than one-third, on average.

One of the concerns with solid fat intake is the concomitant intake of **dietary cholesterol**. Dietary cholesterol is insoluble and esterfied but technically neither a fat nor a lipid. It is a sterol, a chemical ringed structure derived from animal tissues. Plant sterols are also consumed in the diet but are not typically absorbed by the human body.

Beef fat in the diet is mainly provided from middle-aged steer cows that are processed into steak, roast and ground products. The amount and marbling of fat in the meat is the basis for the USDA beef grading system, which designates cattle cuts as quality select, choice, and prime as they increase in fat marbleization. The majority of meats sold and consumed in the US are select and prime choice cuts that are packed and sold raw. Select cuts are often used in formulated products that either do not rely singularly on the texture of the meat or are within moisturizing and meat texturing food systems like soups and sauced meats in frozen meals. Prime grade, young veal, and special breed designations, such as Kobe and Angus, are higher in fat and more marbleized. These cuts are often featured on menus of steakhouses and high-end venue caterers. Ground beef is typically processed from older, tougher cows, and is often higher in total fat than whole, non-comminuted cuts because fat and muscle tissue are ground together. Leaner ground beef simply contains less fat tissue in grinding. Beef fat trimmings are rendered into tallow — historically used in high fat frying. Cooking with tallow waned in popularity as solid, hydrogenated vegetable oils like Crisco hit the scene in the 1950s. Beef that is contained in mixed meal dishes like burritos, sandwiches and rice dishes, as well concentrated beef broths and gelatins, contributes substantially to total solid fat and cholesterol intake in the US. Ground beef, which also includes more cholesterol-rich areas of the animal such as the liver, are prepared into hamburger sandwiches, which are alone a significant source of cholesterol intake in the US.

Pork fat in the diet is provided by fresh and prepared meat. Fresh pork meat cuts vary by their amount of fat per serving. For instance, pork belly meat is composed of nearly 100% fat calories, whereas some cuts from the loin (or back) area have as little as 2.5 grams of fat per 84 gram (3 oz) serving. Other loin cuts, though, like spare ribs, have upwards of 15 grams of fat per serving unprepared. Generally speaking, the meat from the upper loin, shoulder and rump areas of pigs are lower in total fat than underside cuts of pork, and even lower than comparable serving sizes of beef and chicken. In fact, lean pork cuts like pork chops were promoted as “the other white meat” in the 1980s as the pork industry attempted to educate consumers about the number of pork cuts that qualified for UDSA lean designations. Even with promotions to increase fresh pork intake, only around a third of total pork consumed in the US is from fresh pork products. Prepared meats, such as sausage and bacon, provide the larger source of solid fats from pork in the average diet. Pork bacon is fat from the side of a hog that has been smoked and cured in a solution of brine and water. Bacon is the most fat-rich cut of pork, some types providing 83 grams of fat per 84 gram serving. Ham is another, more rose-colored cured pork meat. True ham is pork leg that has been cured and smoked. While there are many types of ham on the market including country, fully cooked, bone-in and sliced ham forms, among others, there isn't much variation in the average 5 grams of fat ham provides per serving; sugar crackled varieties excluded, of course. Sausage, another high-solid fat prepared pork product, varies in fat content per serving. Any portion of federally inspected meat from the animal carcass be used in any amount in sausage, even that portion containing the highest amount of solid fat. Often, trimmed fat byproduct from other processed animal cuts is further added to enhance a sausage's quality. Commercial forms of pork sausage are dominated by patties and links, with many brands blending pork and less fattening meat species, like turkey. Pork meat, including those contained in mixed meals like pizza, soups and sandwiches, and rendered pork fat products (e.g., lard) are responsible for a considerable amount of the total solid fat and cholesterol intake in the US. Americans' pork source of cholesterol is, of course, bacon.

Fat and Cholesterol in Animal Foods

Poultry fat in the diet comes mainly from **chicken and turkey**, with less significant contributions from duck and game birds like geese and quail. There are two types of chickens consumed in the typical American diet: first, broiler/fryer chickens, which are typically six to eight weeks old, weigh around 2 1/2 to 5 pounds, and are widely regarded as more tender, all-purpose birds; and second, roaster chickens, which are larger and older birds with flavorful meat best for braising and stewing. Broad-breasted white turkeys, the primary commercial turkeys in the US, are much bigger in size than chickens, averaging 25 pounds at slaughter. Both types of chicken and turkey contain comparable amounts of fat per serving that vary similarly by body part between the birds. Whole or half breasts with the bone in, or boneless, skinless chicken and turkey fillets provide on average 2.5 grams of fat per serving, whereas thighs, drumsticks and wings, also sold and consumed separately, have a higher fat content, ranging from 6.5-8 grams per serving. Cooking methods for turkey and chicken parts also greatly affect their fat content. Baking, broiling, grilling, and sautéing are the least fattening ways to prepare these meats. Breaded and fried varieties of chicken and turkey can contain as much as 35 grams, or 75% of total calories, from fat. Lean ground turkey, comparable to lean ground beef in total fat content, has replaced a significant portion of the full fat ground beef market over the past few decades. All chicken and turkey, consumed separately or as part of mixed casserole, pasta and sandwich meals, as well as chicken fat-rich broths and stocks, contribute fat intake from meat in the average US diet. Poultry meats, particularly from the thigh, and the yolk from laid eggs are rich sources of dietary cholesterol. Eggs alone provide over 300 mg of cholesterol per one count, and poultry and egg-containing products and mixed meals are also significant sources of cholesterol.

Less significant sources of solid animal fat intake in the US include lamb, seafood, and game animals. Wild game meats have gained popularity in US restaurants as Americans explore cuisines that feature large and lean wild animals including moose, elk, venison (or deer), bison, buffalo, and small lean game like squirrel, rabbit, Cayman alligators and goose. These meats have a fat profile that represents less than 5% of the total weight of the meat and a modest amount of cholesterol. The most common game meat cuts — burgers, roasts, steak and jerkies — provide a modest 1-3 grams of fat per 3 ounces, on average. Seafood is virtually free of solid fat, but it does contribute a significant amount of cholesterol.

Animal milk and milk-derived dairy products consumed separately, and also as part of recipes and mixed meals, constitute approximately one-third of the total solid fat intake in the US. The total fat content of milk and milk dairy products is standardized in the FDA's CFR, and is one of the main criteria for USDA milk grading. Cows are the main source of milk and dairy in the US, but a large variety of non-animal milks, yogurts and cheeses are available alongside animal dairy in full and low-fat versions. Products made with animal dairy ingredients and animal dairy products themselves, especially more concentrated solid varieties such as butter, cheese and yogurt, also contribute a significant source of dietary cholesterol.

Solid fat in **whole liquid milk** is suspended in solution by homogenization or, in non-homogenized milk, atop the water portion as milk fat-rich **cream**. One serving of natural, homogenized whole 3.5% fat milk provides a standardized 8 grams of solid fat. Cream is processed into several dairy products that range in fat content from 10% fat half and half coffee creamers, to 36% fat whipping creams. The serving size for cream and cream products is smaller than for liquid drinking milk to compensate for the concentrated fat calories. Just one ounce of heavy cream contains 12 grams of fat, 2 tablespoons of fermented whole sour cream have nearly 5 grams of fat, and 1/2 cup of whole ice cream has 7 grams of fat. Whole fat milk and milk product markets have grown, even within healthy consumer segments who customarily purchased skim and reduced fat versions touted for containing zero or reduced (5 grams) fat.

Milk products like butter, cheese, and yogurt are distinguished by the degree of separation between their milk fat portion and their liquid portion. To make **butter,** for example, milk is treated to yield buttercream and **skim liquid milk**. Some buttercream is then added back to the skim milk to make 2% **reduced fat milk**, and some is churned in a water-releasing process into butter, which is 80% solid fat by weight. The liquid byproduct of buttercream agitation is buttermilk, which is fermented for drinking and cooking and added to dessert dairy products like ice cream.

Solid fats in whole raw, pasteurized milk can also be precipitated to make various types of **cheese**. Approximately one pint of heat and enzyme-treated milk produces around 2 ounces of solid cheese that is, on average, around 75% fat calories. A standard one ounce serving of cheese generally varies by moisture level, with softer cheese like mozzarella containing around 5 grams, and harder cheese like cheddar providing as much as 10 grams. Cheese is a significant source of solid fat intake in the US. Cheese is eaten as a snack and used in mixed meals like pizza, sandwiches, and pasta dishes.

Yogurt is another milk-derived product whereby acids from fermented milk sugars denature and subsequently coagulate milk proteins, which then trap the milk fat in a semi-solid form. Whole fat yogurt products contain anywhere from 10-20 grams of fat per 8-ounce serving depending on processing method. Like drinking milks, whole fat, full-bodied yogurts are gaining shelf space and consumer interest as an all-natural replacement for higher-fat desserts in the ice cream category. Since lower-fat and fat-free yogurt varieties have dominated the market for over a decade, the increase in full-fat yogurt intake is not yet represented in the stratification of solid fat sources in the US diet.

With few exceptions, plant foods contain negligible amounts of naturally occurring solid fat and cholesterol. **Processed vegetables** though, that are subjected to high-heat frying or chemical hydrogenation treatments, contribute an estimated 25-30% of total solid fat in the average US diet. Recently, the FDA has taken measures to restrict the use of hydrogenated vegetable oils for deep frying to reduce total solid fat intake in the US, targeting mainly French fries which contain approximately 25 grams of fat per serving. In response, quick service restaurants developed lower-fat French fries using combinations of less absorbable frying oils and potatoes engineered to be less absorptive. With little success, these restaurants recently pivoted toward portion size reductions, reducing costs simultaneously.

Hydrogenated and **partially hydrogenated vegetable oils** are also traditionally used as a butter alternative in-home meal preparation, and as a functional ingredient in many commercial foods. Hydrogenated spreads are typically formulated with vegetable oils and come in spreadable, softer market forms in tubs and squeeze bottles, as well as harder forms sold in bulk, (e.g., Crisco). Hydrogenated oils are also used in formulated food products like cookies and crackers, and even in less obvious sources like fruit snacks, dried meal mixes and breakfast cereals. Hydrogenation improves shelf stability, mouthfeel and texture. Recently, food companies have re-formulated many packaged products and menu items to exclude hydrogenated fats as public awareness heightens and labeling laws tighten. Consumer awareness about the dangers of hydrogenated fat is also expressed in the growing demand for non-hydrogenated products featuring separated liquid fat, like jarred nut butters.

Liquid oils are incorporated in the diet by direct consumption of plant and animal tissues and their extracted oil additives. Together, liquid oils represent approximately 13% of total calorie intake in the average American adult diet. While both men and women in the US fall just short of the 27 gram per day liquid oil intake recommendation, they fall well below whole fish and nut intake recommendations. This data suggests that the majority of liquid oil in the US diet is provided by extracted oils used in cooking and formulated food products, not the direct consumption of oil-rich whole foods.

Unlike the animal meats previously discussed, **whole fish** store more fat in liquid than solid fat. Fish are categorized into lean and fatty fish groups. Using a 3-ounce serving size for comparison purposes, leaner species provide, on average, 2 grams of fat per serving, while fattier fish counterparts provide 8-12 grams. The most popular fatty fish in the US is farmed salmon, with just over 11 grams of fat per 3 ounces – more than twice that of fresh Atlantic salmon of a similar size. The leanest fish favorites in the US are tuna varieties, like mahi-mahi, which has less than one gram of fat per 3-ounce serving. Because Americans persistently fall short of eating 8 ounces of fish per week as recommended by intake guidelines, capsulated **fish oil supplements** continue to rise in popularity.

Nuts are among the highest fat plant foods, with high fat species like macadamia and pine varieties providing 20 or more grams of fat per one ounce serving. Common snack nuts like peanuts, cashews, walnuts, and pistachios provide between 10-20 grams of fat per ounce, and when processed, can yield approximately 3 tsp of 100% fat liquid oils. Lower-fat nuts like raw almonds provide 10 grams or less of fat per ounce, with oil roasted varieties containing an additional 1-2 grams of fat per serving. Nuts are processed into many types of products including cooking oils, butters, pastes, and drinking milks. Popular nut oils used in cooking like peanut and walnut oil are favored for light heat sautéing, sauce emulsions, and as moisturizing finishings. The most commonly used nuts for butters and pastes are almonds and cashews which, like oils, contribute approximately 15 grams per two tablespoons. Nut-based drinking milks like almond and cashew have followed low fat dairy production trends by developing varieties that provide 2-4 grams of fat per 8-ounce serving.

Seeds also provide a significant source of liquid fat in the diet and, like nuts, can be processed to yield approximately 3 tsp liquid oil per ounce. A few seeds in the US are popular to eat directly in snacks and meals, like sunflower and sesame seeds. More often, liquid fat from seeds is consumed in the form of cooking oils derived from canola (i.e., cross cultivated rapeseeds), which is a valued ingredient in high-heat culinary applications because of its high smoke point. Cottonseed oil is another significant source of fat intake in the US; however, it is most often used for commercial hydrogenation in snack food formulations and should, for nutritional purposes, be classified with solid fat.

Fruits rarely contain a significant proportion of energy as dietary fat. Two exceptions are coconuts, which are technically classified as solid fats, and avocados. Avocados are a rich source of liquid fat with each half comprising 10 grams of fat and approximately 3 tsp liquid oil. Perhaps a less obvious source of liquid fruit fat is **olives**. The majority of olives consumed in the US have been processed into olive oil. Olive oil is prized for is versatility and flexible taste profile that can be muted, enhanced and paired with most foods with little to no culinary manipulation. Virgin olive oils that have been processed to preserve natural fat profiles and tastes are best for recipes that will be eaten without heat treatment like salad dressings, cold sauces and dips. Virgin oils, while maybe superior in taste, contain the same level of fat as the refined, less expensive, tasteless oil counterparts which are also better-suited for high heat frying and broiling.

Another fruit-sourced oil that is popular in healthy home cooking markets is derived from processing solid coconut fat to yield a product that is liquid at room temperature. **Coconut oil** has a relatively low melt and smoking point that makes it a more flavorful and functional fat additive ideal for low-heat baking, roasting, and quick sauté recipes. Virgin coconut oil is made by cold-pressing the liquid from coconut meat, then separating the oil from the coconut milk and water. Refined coconut oil is most often chemically extracted using a hexane solvent, bleached, and then deodorized so that the characteristic coconut taste and smell are no longer present. (FACTOID: “extra-virgin” on coconut oil labels is virtually meaningless.)

The natural total fat content of vegetables is generally very low with a couple exceptions from the **legume** family. Whole green soybeans (or edamame) provide 6 grams of fat per 3-ounce serving, whereas mature yellow and roasted soybeans provide 8-9 grams per equivalent serving. Most soybeans in the US are processed into soybean oil, which is the number one industrial cooking oil in the US. **Grain** foods, like corn and rice typically contain a modest 1-2 grams of fat per serving.

Liquid vegetable oils are used as functional ingredients in a number of **prepared meals** and **formulated foods** spanning most grocery categories. Prepared meals, like frozen dinners and appetizers and dehydrated box meals, incorporate a wide range of dietary fats. These meals, like convenient single formulated foods, have grown in popularity as meal service has become more time-sensitive. Formulated foods, which include a wide variety of snacks, desserts, sauces, spreads, and salad dressings, are typically consumed as meal accompaniments and between meal snacks and, as such, require more careful scrutiny for fat content.

Snacks and desserts including chips, crackers, popcorn, cookies, candy confections, snack pastries, cakes, and ice cream account for an estimated 40% of total fat intake in the US. Foods in these groups should be consumed discretionally because the fat content is typically high and often devoid of other nutrients. Low-fat and fat-free versions of these typically high-fat snacks have been developed using sweetening and texturing carbohydrates like sugars and starches (link there) to replace the favorable mouthfeel provided in high-fat formulas. Low-fat/no-fat product trends were popular in the 1990s but went out of fashion as the next diet trend, carbohydrate intake reduction, gained notoriety. However, low and no-fat versions of certain products, like salad dressing and mayonnaise, for example, which reduce fat per 2 TBSP serving by 1/3 to 2/3, still occupy the majority of shelf space in their respective categories in grocery stores.

While the solid-liquid designation for dietary fats is the simplest of the fat intake guidelines, fatty acid moieties are of greater nutritional interest. Fatty acids are organic acids characterized by long, unbranched aliphatic carbon chains with an ending carboxyl group. The 3 hydroxyl terminals on the 3-carbon alcohol glycerol connect with the carboxyl group of one of twenty types of fatty acids in a dehydration reaction called, esterification. The dominating fatty acid type in dietary glycerides dictates, in part, the physiochemical and reactive characteristics of solid and liquid fats.

Mono- and di-glycerides are simple lipids that exist naturally in foods in relatively small concentrations. They can also be developed commercially and added to foods for texturizing and emulsification. Made by mixing edible oils with glycerin, mono- and di-glycerides are two of the oldest and most common food emulsifiers. They are widely used in baked products, dairy products and margarine.

Another type of naturally occurring and functional fat that is used to enhance commercial foods, are **phospholipids**.

Phoshatidyl Choline.

Phospholipids are compound lipids that contain di-glcyerides with one hydroxyl terminal occupied by phosphate-containing compounds, like inositol, serine, ethanol amine or choline. The most abundant dietary phospholipid is phosphatidyl choline, found naturally in plant and animal foods, and used in formulated foods for enhanced solubility, homogeneity and consistency. A common application for phospholipids in foods is emulsification of oil-water based solutions needed for many types of prepared products including viscous sauces and salad dressings, and other insoluble, separable ingredient containing products like ice cream, peanut butter, cheese sauce, margarine spreads, chocolate, bread, cakes and even bubble gum.

While there is a small amount of naturally occurring glycerol that contains one or two fatty acids or a phosphate-containing lipid, more than 95% of the fat consumed from foods is comprised of **triglycerides.** The many types of fatty acids that can attach to glycerol in triglycerides are categorized and named by the number, bonding, and positioning of the carbon atoms in the aliphatic chain. And while all foods contain a mix of fatty acid types, the dominating physiochemical features of the fat containing foods are a product of their overall fatty acid profile.

The **number of carbon** in the free fatty chain is the basis for the common nomenclature of fatty acids. The number of carbons in the chain is mainly even numbered and range from 4 to 22. Most dietary fatty acids are long-chain with 18 carbons. Short chain (< 6 C) and medium-chain (6-12 C) fatty acid category rich fats are typically solid at room temperature, like 2 carbon butyric acid found in high concentrations in butter, and medium chained caproic and capric acids dominant in coconut. Long-chain (>12 C) fatty acid categorizations have higher melt and smoke points and are more susceptible to intermolecular forces of attraction.

Differences in the **bonding of carbon** in the fatty acid chain produce various dietary fats with distinctive physiochemical properties. Carbon chains that lack double bonds are called **saturated** because every carbon is saturated with hydrogen, and there is no room for oxidation. Saturated fatty acids are packed tightly together in naturally high concentrations in coconut fat, which is 90% saturated caproic (8:0) and capric acid (10:0). More often, saturated fats are consumed in animal fats, like saturated butyric acid, which represents 70% of the fat in animal milk butterfat (i.e., butter and cheese), palmitic acid (16:0) half of the fats in palm oil, and saturated stearic acid (18:0) highly concentrated in beef tallow, and pork lard, which are each approximately 50% steric acid. Steric acid is the most prevalent saturated fat in the US diet and it is consumed in animal meat (i.e., hot dog), multi-meat and cheese mixed meals like sandwiches (i.e., bacon cheeseburger) and pizza (i.e., sausage), which provide on average around 12 grams of saturated fat per serving. Ice cream and cake desserts that are made with butter are also rich sources of saturated fat and contributes a huge range from 2 to 20 grams of saturated fat per serving. Americans exceed the recommended 10% saturated fat calories restriction by approximately one percent, with a total of calories 11% of total calories from saturated fat.

The most abundant dietary fatty acids are **unsaturated**, meaning there is at least one double bond or more in the carbon chain. The double bonds present in unsaturated fatty acids are naturally in the cis position, which means the hydrogens are positioned in a way that yields a less compact and less dense fatty acid that is liquid at room temperature. Most fats humans consume are unsaturated long chain fatty acids and are categorized into 3 primary families classified by their double bonding positioning nomenclature.

Omega 9 fatty acids have a double bond between carbon 9 and 10 (starting from the carboxylic acid end closest to glycerol). **Oleic acid** is the most abundant naturally occurring dietary monounsaturated fatty acid (MUFA) that is found in naturally high concentrations in whole foods such as **avocados**, **olives** and **sunflower seeds**. The primary source of oleic acid in the US diet, however, is from cooking oils like safflower oil and olive oil, which both contain nearly 75% oleic acid; other high oleic seed and nut oils are derived from canola/rapeseed and peanuts, which contain 50-70% oleic acid by total weight. High oleic oils (70%) are also developed by chemically saturating some of the double bonds in high polyunsaturated fat oils (e.g., safflower, sunflower and soybean) to formulate highly monounsaturated oils that can be used in healthier mayonnaises and dressings.

Polyunsaturated fatty acids have two or more double bonds. **Omega 6,** or linoleic acid (18:2), is the most abundant dietary essential fatty acid characterized by a double bond between carbon 6 and 7. **Linoleic acid** is prevalent in certain **whole nuts** and seeds which provide anywhere from 5-10 grams of n-6 per one ounce serving. The richest whole nut sources are pecans and walnuts, which have a fatty acid profile of more than 40% n-6, on average. Peanut butterfat is approximately 30% linoleic acid, and is a significant source of total linoleic acid intake in the US. The most concentrated source of natural linoleic acid is the oil derived from **sunflower seeds**. Pure sunflower seed oils contribute approximately 75% of calories from linoleic acid. Walnut, corn, soybean and cottonseed oils are other significant sources of n-6 providing approximately 50-55% n-6, or approximately 7 grams of n-6 per tablespoon.

Plant fats also contain, in much lower concentrations,
omega 3 polyunsaturated fatty acids, which have the first double bond between carbon 3 and 4. Dietary omega 3, or alpha linoleic acid (18:3), must be consumed in the diet from rich plant sources like nuts, seeds, grains, legumes, dark green vegetables and their derivative germs and oils. The richest known plant source of omega 3 fatty acids are **flaxseeds**, which contain 6.5 grams of omega 3 per one ounce serving. Flaxseeds and other omega 3-rich nuts and seeds are increasingly featured in products like breads and cereals and used to enhance the omega 3 content in cooking oil for dressings and sauces.

Other whole food sources rich in omega 3 are **walnuts** and walnut oil, which provide around 1.5 grams of omega 3 per standard TBSP serving. Canola and soybean oils consist of just 10% n-3, but because they are used in so many products, these oils are a significant source of n-3 in the US. Rich plant sources of n-3 include **chia seeds**, kale and spinach all rising in popularity as well as less popular exotic foods, like seaweed. Omega 3 fortified dairy products like yogurt contain around 30 mg, which is relatively insignificant.

In animals, mainly **seafood**, a portion of the ALA is converted to longer and further de-saturated fatty acids, DHA and EPA. The richest dietary source of pre-formed DHA/EPA is from seafood (i.e., oysters and fish). Salmon is the most concentrated source of pre-formed n-3, providing on average 2 grams DHA/EPA per 3-

ounce serving. Water temperature and habitat influences the DHA/EPA content of fresh fish. Pacific-sourced fish source contain less DHA and EPA than colder water Atlantic salmon, and farmed salmon provides more EPA/DHA than wild salmon varieties. Other fish species high in pre-formed DHA and EPA include trout, herring, tuna, and mackerel, swordfish, tilefish, shark, which each provide in the range of .75 to 1 g DHA and EPA per 3 ounce serving. DHA/EPA-fortified foods are naturally not vegan and are marketed mainly using the more mainstream omega 3 designation. For instance, "Omega 3-rich" eggs are actually providing mostly pre-formed DHA/EPA (produced by DHA rich hen diet) in concentrations around150 mg of DHA/EPA per egg. DHA/EPA supplements provide about 300-500 milligrams of DHA and EP, which is adequate to meet the .3 mg/day direct DHA/EPA intake guideline.

Unsaturated fatty acids are also classified in terms of their **hydrogen positioning.** Naturally occurring double bonds are typically flanked by hydrogens in the cis position, which results in a kinked fatty acid chain. Hydrogenating the unsaturated double bonds alters the configuration of hydrogen from the cis to the trans position. That imparts solid fat characteristics to liquid oils. Although food manufacturers and restaurants are more aware now of the trans fat content of their products, hydrogenated oils remain the largest source of trans fat in the US diet, by far. Naturally occurring **trans fats** exist in concentrations ranging from approximately 10-15% of the total unsaturated fatty acid content in meat and dairy products from "ruminant" animals. Even with higher than recommended meat and dairy intake, natural trans fats contribute less than 20% of the total trans fats intake in the US. This estimation does not include supplemental conjugated linoleic acid (CLA) a naturally occurring trans-fat popularized in fitness and sport nutrition markets.

3.2 Homework 1

Homework • Unanswered

Touch on the processed foods that you think would have hydrogenated fats

✓ Correct!

Targets placed: 0/6

Undo Delete selected Remove All

You can place up to 6 targets

Explanation

All of these products have hydrogenated ingredients

Answered - Correct!

1 attempt left Retry

3.2 Homework 2

Homework • Unanswered

Put these dairy products in order from low to high fat (lowest fat at the top to highest fat at the bottom)

1	D	Skim milk
2	B	Whole milk
3	A	Half and half
4	C	Butter

Explanation

Skim milk (0%)
Whole milk (3.5%)
Half and half (10%)
Butter (80%)

Answered - Correct!

1 attempt left Retry

3.2 Homework 4

Homework • Unanswered

Match each oil to the fatty acid that it features in the highest concentration

Premise		Response
1 Olive oil	→	A Oleic
2 Soybean Oil	→	B Linoleic
3 Walnut oil	→	C Alpha linoleic

Answered - Correct!

1 attempt left Retry

3.2 Homework 5

Homework • Unanswered

Coconut, butter, and lard are all similar in that their fatty acid carbon chemistry is predominantly ______________ .

- A saturated
- B medium chained
- C trans configured
- D unsaturated

Explanation

All three are high in fatty acids that are saturated with no double bonds. The physical state of these three fats at room temperature is solid.

Answered - Correct!

1 attempt left Retry

3.2 Homework 6

Homework • Unanswered

Match a food to its concentrated fatty acid type.

Premise		Response
1 Beef	→	D stearic acid
2 Avocados	→	E omega 9 / oleic acid
3 Peanut Butter	→	C omega 6 / linoleic acid
4 Flax seeds	→	A omega 3 / alpha linoleic acid
5 Salmon	→	B pre-formed omega 3

Answered - Correct!

1 attempt left Retry

3.3 Fat and Lipid Processing

The processing of dietary fats and lipids is more complicated than carbohydrate and protein processing because lipids, as they are consumed in the diet, are insoluble in the aqueous portions of the human body. Additional emulsification and packaging processes, as well as an alternate transportation routes are necessary to effectively process fats and lipids.

Digestion of dietary fat begins in the mouth with chewing and mixing of foods with salivary enzymes. **Lingual lipase** hydrolyzes, or cleaves, fatty acids from glycerol, to transform a small amount of the ingested dietary triglyceride to free fatty acids and di-glycerides. The insoluble fats and lipids, including cholesterol and phospholipids, join together in the bolus for the journey down the esophagus to the stomach.

Fat droplets remain relatively aggregated throughout the mixing process in the stomach while a small amount of exteriorly positioned triglycerides is cleaved by acidic **gastric lipase**. Next, these large droplets of cholesterol, triglycerides, diglycerides and free fatty acids of varying lengths and saturation all enter the duodenum of the upper small intestine. Stored bile is released from the gallbladder into the lumen of the small intestine to emulsify the large, insoluble fat droplets into micelles, which are many small droplets that are suspended in aqueous solutions. The small droplets provide a more adequate surface area for action of **pancreatic** and intestinal lipase, which hydrolyses remaining triglycerides and diglycerides to monoglycerides and free fatty acids. The droplets are also sequestered by pancreatic phospholipase and cholesterol ester hydrolase to hydrolyze phospholipids and cholesterol.

Mono-glycerides, free fatty acids and cholesterol are all absorbed as **micelles** by **diffusion** into the mucosal lining and epithelial cells of the small intestine. Short and medium-chain free fatty acids are absorbed into the capillary network and directed to the liver while bound to the protein, **albumin**.

Long-chain free fatty acids and monoglycerides enter the cell's lipid synthesizing endoplasmic reticulum, where they are re-formed into **triacylglycerides (TAG)**, largely through the 2-monoacylglycerol pathway and cholesterol esters by acetyl co A: cholesterol acytltransferase. Upon exiting the endoplasmic reticulum, TAG, cholesterol esters and phospholipids are collected into a lipoprotein compound for **endocytotic absorption** by lactille networks collecting in the lymphatic system.

Figure 3.6. Chylomicron travels general circulation and drops off fatty acids to tissues that process and store fats

Chylomicron lipoproteins are equipped with several signaling proteins, or **apolipoproteins**, and have a triaceylglyceride-rich, non-dense composition. The lipoprotein travels through the lymph system to the subclavian vein to the thoracic duct, where it is pumped through the heart to general circulation. From there, chylomicrons are directed to tissues that use free fatty acids for respiration, and to tissues that convert lipids to stored energy, hormones and structural matter.

In the arterial capillary walls, the traveling chylomicron comes into contact with the enzyme **lipoprotein lipase** (LPL). LPL activates signaling **apolipoproteins** on the surface of the chylomicron to initiate the hydrolysis of free fatty acids and glycerol. Free fatty acids are released from the chylomicron and taken up by cells in the vicinity. Once the majority of triglycerides in the chylomicron have been removed, a smaller, denser, remnant returns to the liver. The liver receptors also respond to signaling apoliporpoteins and the remnant enters the liver for processing.

The hepatocytes of the liver produce and package fats and lipids for transport in general circulation much like the enterocytes of the small intestine. Fatty acids delivered from general circulation and long chain fatty acids and cholesterol esters in the chylomicron remnant are processed by the liver to the two-carbon fatty acid **acetyl Co A** in a process called **lipogenesis**. If blood glucose is in excess, the liver also converts excess glycolysis intermediate, pyruvate to Acetyl Co A, which is then converted to back to cholesterol by **HMG Co A reductase** for bile acids synthesis or, in most instances, to longer-chain fatty acids that are re-packed by the hepatic Golgi bodies into triaceylglyceride. New triacylglyceride (TAG) and cholesterol esters are integrated into **very low-density lipoprotein (VLDL).**

VLDL is comparable to the chylomicron in size and density and in that it is equipped with several **apoproteins** for cellular communication and certain **phospholipids** for solubility in aqueous solutions. VLDL responds similarly to **lipoprotein lipase** for tissue-specific fatty acid drop off, and thus also grows denser as it travels though circulation. As TAG inside of VLDL are hydrolyzed and free fatty acids and glycerol are released, intermediate and **low-density lipoproteins** (LDL) are formed. LDL is more protein and cholesterol rich, as it also supplies the most cholesterol to adrenal tissues. Remaining cholesterol is removed from LDL in a receptor mediated processes, and then directed back to the liver for recycling by a **high-density lipoprotein** (HDL) carrier.

In the subcutaneous region, a small amount of **post-absorptive** fatty acids undergo mitochondrial lipolysis and oxidation to sustain the cell's energy needs, but most undergos insulin-stimulated compact **TAG synthesis**.

In times between meals, epinephrine and glucagon stimulate **TAG lipolysis. The hormones** activate kinases and cytokines in the adipose tissue that initiate **hormone-sensitive lipase** (HSL) to hydrolyze free fatty acids from glycerol. Free fatty acids released from adipose tissue travel bound to albumin through the general circulation in route to muscle cells or other lipid catabolizing tissues.

Fat oxidation and the carnitine transport system

Cardiac and skeletal myocytes absorb circulating free fatty acids at a rate that is proportional to serum free fatty acid concentrations. Long carbon chains are transported into the cell mitochondria by **carnitine shuttles** that are embedded along the inner and outter mitochondrial membranes. Inside the mitochondria, the chains are shortened into 2-carbon units of acetyl Co-A in the **beta-oxidation** (i.e. fatty acid spiral) cycle, and subsequently reduced in the TCA cycle and the electron transport chain (ETC). Shorter and medium-chain fatty acids are granted access across the membrane shuttle-free, so that when MCT intake is high, acetyl Co A can accumulate. The excess acetyl Co A is condensed to ketones, which, depending on the metabolic circumstances are oxidized for energy or converted back to intramuscular triacylglycerides.

In most types of cells of the body polyunsaturated fatty acids (PUFA) are converted to longer and more desaturated fatty acids. **Linoleic acid** (LA) is elongated by 2 carbons and desaturated with one double bond by desaturase enzymes to form **arachidonic acid** (AA). Most

LA and LA-derived PUFAs are either integrated into cell membrane phospholipids or used in the cellular production of the major eicosanoids, prostaglandins, leukotrienes and thromboxanes. **Alpha-linoleic acid** (ALA) is also desaturated and elongated by 2 carbon using the same pathways and enzymes to **Eicosapentaenoic acid** (EPA). EPA, like AA can be converted to eicosanoids, or it can be elongated by 2 C and de-saturated by one more double bond, to make **Docosahexaenoic acid** (DHA). The majority of long-chain DHA is integrated into membrane phospholipids of high-fat tissues of the brain, eyes and nervous system.

3.3 Homework 1

Homework • Unanswered

Match each digestive compound to its fat digestion function.

Premise		Response
1 Bile	→	A emulsifies large fat globules for enzymatic action
2 micelle	→	C traps small fat globules for intestinal absorption
3 chylomicron	→	B transports fats into circulation
4 lipase	→	D hydrolyzes fatty acids from glycerol

Explanation

Bile - emulsifies fat into smaller drops
Micelle - traps globules for absorption
Chylomicron - transports fat into circulation
Lipase- hydrolyzes fatty acids from glycerol backbone

Answered - Correct!

1 attempt left Retry

3.3 Homework 2

Homework • Unanswered

After dropping off fatty acids to tissues throughout circulation, the chylomicron remnant returns to what organ for processing?

- A brain
- B heart
- C liver
- D pancreas

Explanation

The remnant is returned to the liver - The liver degrades chylomicron remnant and uses the bio-materials to synthesize lipoproteins, cholesterol, and bile.

Answered - Correct!

1 attempt left Retry

3.3 Homework 3

Homework • Unanswered

Lipogenesis takes place primarily in the _____________ tissue; and beta-oxidation primarily in the mitochondria _____________ cells.

A muscle adipose

B adipose muscle

C adipose brain

D muscle brain

Explanation

Fat tissue adipocytes are the primary lipogenic tissues, and muscle cell mitochondria is the primary location for fat oxidation. The brain doesn't oxidize fats directly.

Answered - Correct!

1 attempt left Retry

3.4 Fat and Lipid Function

The basic organic elements provided by endogenous and exogenous fats and lipids are used in a large number of metabolic and biological reactions that sustain human life. The solubility, large size and reactivity of the carbon chains in fats are critical in the provision of energy, structural integrity, and functionality of dietary fats in the human body.

Fat is a dense and **concentrated energy** source that can be stored in high quantities in the body without water and thus with very little cellular osmotic pressure. Fat is the **primary fuel substrate** for the majority of resting bodily activities and the preferred fuel substrate for myocardial (i.e., heart) cells. Each gram of dietary fat contributes **9 energy calories** and each unit of Acetyl CoA that is reduced in the TCA cycle and ETC yields a net **460 ATP**. While this amount is more than ten times the ATP yielded energy derived from oxidation of glucose (i.e., pyruvate), the utility of fatty acid oxidation as an efficient fuel substrate is conditional and limited in use if oxygen is insufficient, like in the case of high-intensity muscle work or cardio-pulmonary diseases.

Figure 3.10. Fatty Acids are energy dense and the preferred fuel source at rest

Lipids are easily converted to a compact and large reservoir of **stored energy** in a process called lipogenesis. While muscle tissues are limited in the amount of lipid that can be stored as triglycerides (TAG), adipose tissues can accommodate enough stored TAG to exceed tens of thousands of chemical energy calories, or put another way, enough to fuel hundreds and hundreds of miles of kinetic movement. In times of highly-restricted dietary carbohydrate intake, glycerol and fatty acids that are stored in the body can also be converted to carbohydrate substitutes in the **guconeogenic pathway**, which supports the brain and other glucose-dependent nerve tissues. This function is critical to the survival of glucose-dependent tissues in instances of semi starvation or strict calorie-controlled diet plans.

Dietary fats and lipids are not just a source of cellular energy; they also function as building blocks in cellular and molecular **structures** that provide the body protection, insulation and integrity against physical forces. The most fat-dependent structures in the human body are animal **cell membranes** that are made of semi-insoluble, semi-impermeable bi-layers that feature phospholipids, free fatty acids and cholesterol. The lipid membranes around the cells physically separate the inside from the outside of the cell. They also control the movement of substances in and out of the cells which dictate the length and saturation of the fatty acids in the phospholipids. The structural cholesterol through the bilayer affects the arrangement of the membrane and thereby its fluidity and permeability. Shorter chain fatty acids and unsaturated fatty acids are less stiff and less viscous, making the membranes more flexible. This influences a range of important biological functions such as the process of endocytosis in which a cell wraps itself around a particle to allow its uptake. Oleic acid is the most prevalent fatty acid in total body cell membranes, but certain body tissue membranes are higher in docosahexaenoic acid (DHA). DHA and other ALA derived fatty acids represent around 10% of the total body cell membrane matter and, depending on intake, up to 30% of the membrane matter of the retina (i.e., eye), nervous tissue and spermatozoa. Membrane DHA also provides a reserve in the case of limited essential fatty acid intake.

Figure 3.11. Cholesterol Functions

In addition to providing energy and structural materials, dietary fats and lipids also play **functional roles** in facilitating and supporting many bodily reactions. For instance, cholesterol (i.e., bile) aids in the absorption of fats; dietary fat aids in the process of satiation by delaying stomach emptying; and adequate intake of total dietary fat helps to ensure adequate fat-soluble vitamin absorption and status. Intake of cholesterol, like plant sterols, may also play a role in regulating the absorption of dietary cholesterol and bile salts by promoting the expression of a gene for a cholesterol exit shuttle that moves absorbed cholesterol from enterocyte back into the lumen where it will move along for excretion. Cholesterols, mainly from endogenous sources (1000 mg/day versus 250 mg/day in diet), are also direct precursors to adrenal-derived sex steroid **hormones** and **Vitamin D,** and is also in high concentration in the CNS as a large constituent of the grey, myelinated matter of brain and nerve tissue. The grey matter is critical in **CNS communications** and speed of message delivery.

More direct functional roles of endogenous and exogenous fat and lipids includes a contribution of organic matter for synthesis of genetic, enzymatic, hormonal and immune system-dependent substances. LA-derived ALA, for example, is important in **gene expression** for receptors that are involved in long chain fat metabolism. The mechanisms by which ALA are involved are not yet entirely clear; however, it is suggested that it is at least partially through an increased expression of enzymes needed for insulin-stimulated adipogenesis. LA and ALA metabolites also play a role in preserving the **epidermal water barrier** that keeps skin moist and supple, and can also **minimize inflammatory responses** through elongation and desaturation pathways that form eicosanoids. **Eicosanoids** are hormone-like substances (i.e., prostaglandins, leukotrienes and thromboxines) that are critical for platelet aggregation, hemodynamics and cardiovascular tone.

Figure 3.12. Cell Membrane and Structure and PUFA supply

3.4 Homework 1

Homework • Unanswered

Stored fat has slightly more than ______________ times the energy density of other stored nutrients.

- A 1.5
- B 2
- C 3
- D 4

Explanation

Stored fat has an energy value of 9 calories per gram compared to 4 that is available from carbohydrate combustion

Answered - Correct!

1 attempt left Retry

3.4 Homework 2

Homework • Unanswered

What cell structure is made primarily of fat?

- A mitochondria
- B cell membrane
- C cytosol
- D nucleus

Explanation

Fatty acids comprise the lipid bilayer of cells. The type of fatty acids in the diet influences cell membrane composition

Answered - Correct!

1 attempt left Retry

3.5 Fat and Lipid Status Measures

Unlike glucose, the levels of dietary fat in the human body are not so tightly regulated. Imbalances between the physiological need and intake of fat and cholesterol can lead to changes in anthropometric, biochemical and clinical assessment measurements.

Long-term excesses in dietary fat calories can lead to **excess body fat accretion**. An average percentage for healthy body fat ranges from 15-20% for men, and due to a lower proportion of total lean mass and extra maternal fat, 20-30% for women. Elevated levels of stored body fat, especially in the visceral (non-subcutaneous) region, often have serious biochemical manifestations that are involved in the pathogenesis of **metabolic diseases** that stem from insulin resistance, reduced serum leptin sensitivity, and metabolic dyslipidemia.

Dyslipidemia is a significant biochemical change in blood cholesterol levels. **Blood cholesterol** is the net result of the absorption in the gut and the synthesis in the liver, minus the excretion via the feces and the use of cholesterol by cells. While eating foods that contain cholesterol has little effect on blood cholesterol levels in healthy adults who effectively regulate cholesterol status through intestinal excretion and limiting endogenous production, in individuals with dyslipidemia, increased cholesterol intake results in the net increase in endogenous cholesterol production as well as suppression of LDL receptor expression and activity, which exacerbates elevated levels of serum cholesterol.

Serum cholesterol measurements are indicative of hepatic lipoprotein synthesis and are typically evaluated as the sum of the lipoprotein subtractions, VLDL, HDL, and LDL. LDL is the dense cholesterol-rich fraction that is elevated in high saturated and trans fat diets. Excess saturated fat or trans fat in the diet also results in a higher proportion of solid fats being integrated into cell membranes and inner-cellular TAG, so that cells are more **insulin and LDL receptor insensitive.** Thus, diets high in saturated and trans fat specifically result unfavorable biochemical outcomes centered on increasing serum cholesterol.

While most often imbalances in EFA are deficiencies, there are instances in which excesses in EFA intake can have negative biochemical and clinical outcomes. Most relevant in the cases with high levels of supplemental n-3 and DHA. N-3 competes with the same desaturating and elongation enzymes that convert ALA to AA. The result is decreased serum AA concentrations, and in more rare and severe cases, clinical dermatitis. DHA in excess on the other hand, leads to elevated and imbalanced levels of serum levels of AA from the retro-conversion of DHA to EPA. Excess intake of even healthy fats can be deleterious as accumulating acidic ketones produced from condensing excess acetyl co A appear in the blood and urine.

In instances where fat intake is limited between meals and during fasting, reliance on free fatty acid oxidation and lipolysis increases, and glucose utilization slows in all tissues except the brain and red blood cells. For this reason, elevated FFA are not indicative of dietary fat intake, rather a lack of total energy of carbohydrate intake. Long term fat restrictions have been reported to initiate diarrhea and fat malabsorption.

Essential fatty acid deficiencies are extremely rare in the US due to the large storage of bioactive fatty acid pools available in cell membrane lipid bi-layers. However, since mammalian cells do not have enzymes to insert a cis double bond at the n-6 nor n-3 position, both essential fats, linoleic acid and alpha-linolenic acid must be consumed in the regular diet. Instances of diseases that result in fat malabsorption or impaired utilization or prolonged durations or restrictions in EFA result in biochemical and clinical outcomes that are related to growth, immunity, and even behavior.

In the case of limited intake of or absorption of LA is impaired, AA synthesis reduced and the ratio of eicosatrienoic acid (EA): arachidonic acid (AA) is increased. Clinical diagnosis of n-6 deficiency can be made with a serum EA : AA ratio greater than .4. The symptomatic manifestations of n-6 deficiency include **scaly skin**, **rash**, **dermatitis**, transepidermal water loss, **reduced growth** and **diminished immune response**. Clinical manifestations of prolonged n-3 deficiency result in reduced serum DHA, which has a comparable diminished immune response to n-6 deficiencies, plus reduced **visual acuity**, and deleterious changes in **learning behaviors** including analytical problem solving and speech. Behavior and visual changes are attributed to lower DHA content of grey matter of brain and retinal membranes.

3.5 Homework 1

Homework • Unanswered

While fatty acid deficiencies are uncommon in the US, if this type of fatty acid is restricted from the diet, diminished immune response can occur.

- ○ **A** transfat
- ○ **B** cholesterol
- ◉ **C** essential fats
- ○ **D** polyunsaturated fat

Explanation

Essential fats must be consumed in the diet

Answered - Correct! 1 attempt left Retry