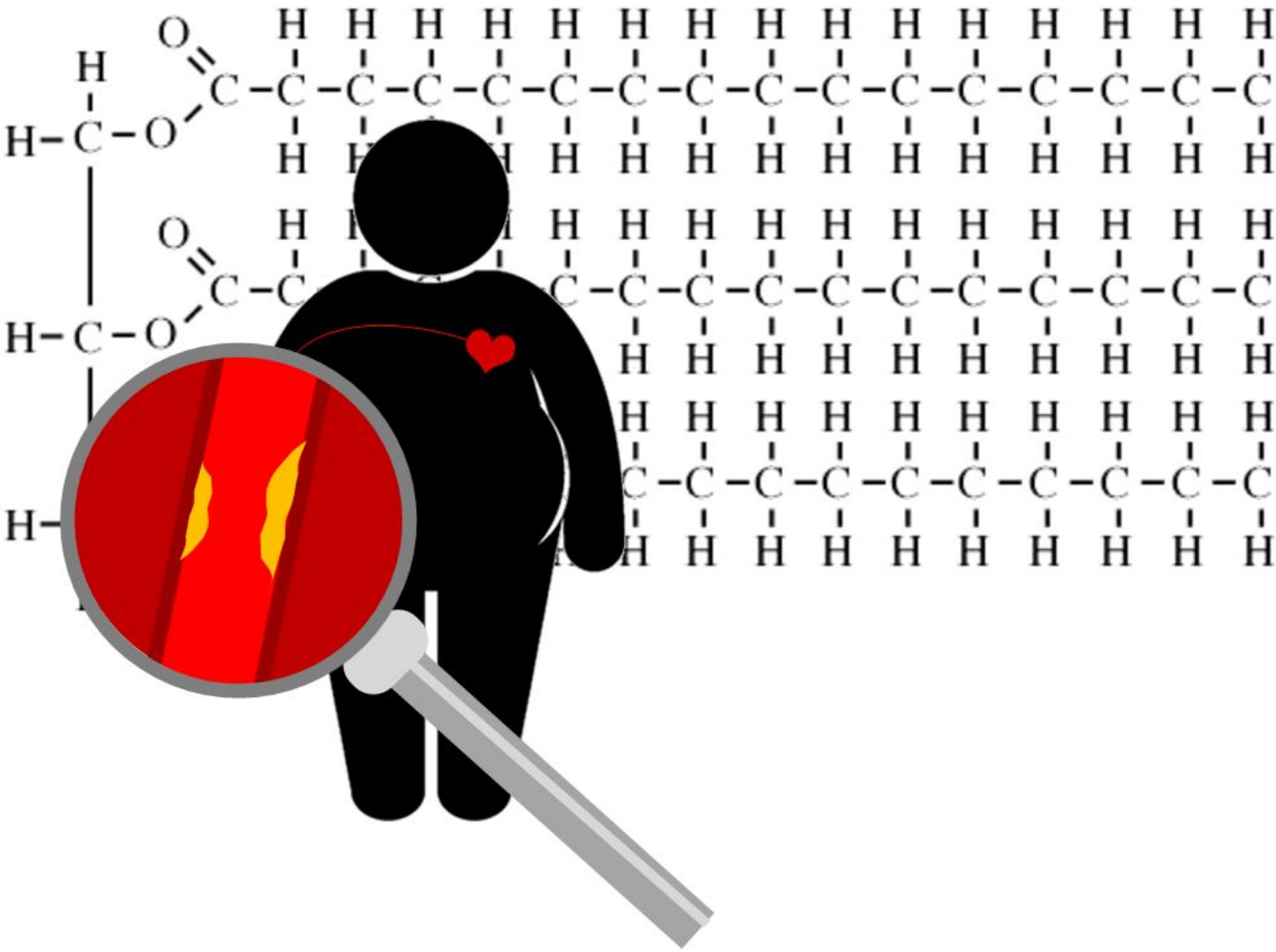
Fat intake related cardiovascular disease

Cause, prevention and cure of cholesterol related hypertension



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Summary

In this research paper the relationship between blood pressure and fat intake is explored. The purpose of this research is to gain knowledge on cardiovascular disease as a result of fats and hereby lower the prevalence of this disease. In food, different types of fat are present, for example saturated and unsaturated fats, in which cis and trans fats form subgroups. Fats are digested in several steps. After they are digested and emulsified, they are directly discharged into the blood circuit. They are transported by lipoproteins, such as chylomicrons and cholesterol. Different types of fat have different effects on the HDL/LDL-cholesterol ratio in the blood. Unsaturated cis fats are known to improve the ratio, saturated and trans fats influence the ratio in a negative way. LDL-cholesterol forms plaque in the arteries, which increases the blood pressure. This claim is tested in an experiment. The pressure in a tube, serving as model for a blood vessel, is measured. To simulate the plaque, a hose clamp is placed to create a narrowing. Based on the results, the effects of the condition and methods for prevention and cures are given.

Introduction

The advertisement of Becel Pro-activ can be seen regularly on Dutch television. The advertisement claims that the product lowers the risk of cardiovascular disease. Becel Pro-activ contains phytosterol, which decreases the amount of cholesterol in the blood, according to 45 studies.[1] Cholesterol is a type of fat.[2] It remains unexplained how cholesterol increases the risk of cardiovascular disease. Moreover, it is unknown if the claim of the commercial company is valid.

Additionally, cardiovascular disease is the cause of 100 deaths a day in the Netherlands only.[3] According to estimates, high blood pressure is the cause of 49% of cardiovascular disease related deaths.[4] Gaining knowledge about cardiovascular disease is therefore vital. This research paper focuses on the relationship between high blood pressure and fat intake.

Research question

The research question of this paper is:
How is blood pressure affected by fat intake?

Subquestions

To investigate the correlation between fat and blood pressure, first information on blood vessels and types of fat was needed. The subquestions "*What is the human blood circulation?*" and "*What types of fat enter the human body?*" were composed. Also, knowledge of how fats are handled was required. This resulted in the third subquestion "*How is fat processed by the human body?*"

During investigating these questions, two major new questions arose: "*What are the causes of a high LDL-cholesterol percentage in the blood?*" and "*How are the blood vessels being clogged?*". Also, the question introducing the experiment "*What is the influence of a clogged blood vessel on the blood pressure surrounding that clog?*" was formulated.

Knowing about the causes, knowledge on the effects and prevention of high blood pressure was gathered answering the subquestions "*What are the effects of high blood pressure on the human body?*" and "*How can high blood pressure be prevented?*"

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[1] Youtube, Becel pro-activ (11-01-2013). *Commercial echte mensen Becel pro-activ.* Retrieved on 31-01-2017, from https://www.youtube.com/watch?v=gw8WmPID_v0
[2] Wikipedia (27-01-2017). *Cholesterol.* Retrieved on 31-01-2017, from https://en.wikipedia.org/wiki/Cholesterol
[3] Hartstichting. (n.d.) *Wat we doen.* Retrieved on 31-01-2017, from https://www.hartstichting.nl/wat-we-doen
[4] Dietcetera. (n.d.). *Hoge bloeddruk (hypertensie).* Retrieved on 31-01-2017, from https://www.dietcetera.nl/ziektes-en-aandoeningen/hoge-bloeddruk-hypertensie

Hypothesis

The hypothesis of this research paper is: *fat can cause a blockage in the blood vessel, resulting in an increase in blood pressure before the blockage.* This theory is based on a garden hose swelling up when stepped upon. The water is pumped through the narrowed part with a higher force, since the same amount of water needs to pass through a narrower passage. The water accumulates before the narrowing and more water is entering the hose every second. This increases the pressure on the hose, resulting in it stiffening and swelling. The blood vessel is expected to work the same way.

Expectation

The hypothesis is tested in an experiment, using a model of a blood vessel in which the pressure can be measured. The expectation is: *if fat causes a blockage in the vessel, which increases the blood pressure before the blockage, then the pressure in the model with a blockage will increase before that blockage*.

An asterisk (*) is placed behind difficult words. Starting at page 60 is a word list with these words and their definition in alphabetical order.

1 Types of blood vessels and their function

1.1 Blood

The human body is filled with approximately 5 litres of blood. Blood consists of a liquid called blood plasma* and of various solid constituents like red and white blood cells. Red blood cells contain haemoglobin* and are the main means of transport for oxygen in our bodies. White blood cells help fight infections by attacking the invaders of the body. Blood plasma* is mainly built up of water in which many substances are dissolved, for example oxygen, carbon dioxide, nutrients and waste products, enzymes*, hormones* and antibodies* are all dissolved in blood plasma* and transported through the body this way. Substances that are difficult to dissolve are bound to special proteins in the blood plasma* and form lipoproteins*, the function of which is explained in chapter 4.[5]

1.2 Blood circulation

The heart pumps blood through the body. Humans have a double circulatory system*, meaning that blood passes through the heart twice per cycle. It first enters the pulmonary circuit* and is transported through the lungs where it is oxygenated, meaning that oxygen is bound to the haemoglobin* in the red blood cells in the blood plasma*. The blood flows back to the heart and is then pumped into the systemic circuit*. This circuit guides the oxygenated blood to all the organs. The organs and tissues use the oxygen and the blood returns to the heart as oxygen-poor.[6] This process is repeated approximately every minute.[7]

1.2.1 Heart

The human heart consists of a separated left and right half. Both halves are divided into a atrium* and a ventricle*, the atrium* lying on top of the ventricle*. Blood poor in oxygen from the body enters the heart through the venae cavae* into the right atrium*, which pumps the blood to the right ventricle*. The right ventricle* pumps the blood into the lung artery* to the lungs. The oxygenated blood from the lungs enters the heart in the left atrium* via the lung vein*. The left atrium* pumps the blood into the left ventricle*, which pumps it into the arteries*, to the body.[8] Figure 1 is a schematic drawing of the heart.[9]

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[5] Bos, A., Gommers, M., Jansen, A., Kalverda, O., Rouw, T. de., Smits, G., . . . Westra, R. (2012). *Biologie voor jou, leeropdrachtenboek 6 vwo.* 's-Hertogenbosch: Malmberg

[6] IvyRose. (n.d.). *Double Circulation.* Retrieved on 31-12-2016, from http://www.ivyroses.com/Biology/Transport/Double-Circulation.php

[7] Brain, M. (30-09-2015). *How fast does blood flow throughout the human body?* Retrieved on 31-12-2016, from http://www.brainstuffshow.com/blogs/how-fast-does-blood-flow-throughout-the-human-body.htm

[8] Bos, A., Gommers, M., Jansen, A., Kalverda, O., Rouw, T. de., Smits, G., . . . Westra, R. (2012). *Biologie voor jou, leeropdrachtenboek 6 vwo.* 's-Hertogenbosch: Malmberg

[9] Modell, H.I. (01-06-2007). *Helping students make sense of physiological mechanisms: the "view from the inside".* Retrieved on 02-01-2017, from http://advan.physiology.org/content/31/2/186

1.2.2 Arteries

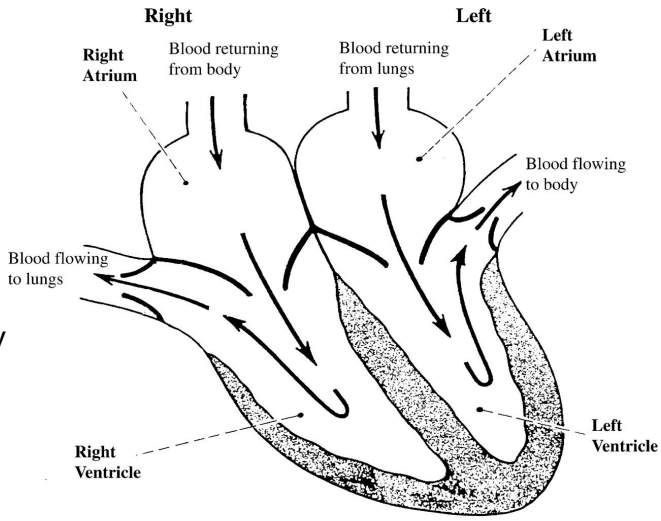

Figure 1: the heart and blood flows

Oxygenated blood leaves the heart through the aorta, the main artery* of the body. Since the heart pumps the blood in a pulsing way through the arteries*, the arteries* face a fluctuating force. Muscles in the artery* walls hold the vessels in shape when facing the force, which is why arteries* have thick and elastic walls. The pressure when the heart contracts is called the systolic pressure*. In the aorta, this pressure is highest. Between two pulses the pressure drops. The lowest pressure in the arteries* is called the diastolic pressure*. The blood pressure in arteries* branching out from the aorta is also high and pulsating. When arteries* are damaged, blood flows out fast due to this high pressure. A great blood loss can be lethal. To prevent the arteries* from such dangerous damage, they lie deep in the body.[10] An exception is the radial artery* in the forearm, which lies just beneath the skin and makes it possible to measure the heart rate at the wrist.[11]

1.2.3 Arterioles

In the organs, the arteries* branch out into smaller blood vessels called arterioles*. The blood pressure is lower than in the arteries*. The wall of the arterioles* is much thinner than the wall of the arteries* and mainly consists of smooth muscle tissue. This muscle tissue enables the arterioles* to widen or to narrow. This is called vasodilation* and vasoconstriction*, respectively.[12] These changes in diametre determine the blood supply of the different regional circuits.[13] One of the ways this system is put to practice is in regulating the body's temperature. When the brain notices that the temperature is too high, it sends impulses to muscles in the arterioles* in the skin, which results in dilation or widening. This means that blood flow increases beneath the skin, resulting in a greater heat loss. When the body temperature is low, the arterioles* in the skin are constricted, reducing the blood flow and heat loss.[14]

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[10] Bos, A., Gommers, M., Jansen, A., Kalverda, O., Rouw, T. de., Smits, G., . . . Westra, R. (2012). *Biologie voor jou, leeropdrachtenboek 6 vwo.* 's-Hertogenbosch: Malmberg

[11] Wikipedia. (29-06-2016). *Radial artery*. Retrieved on 31-12-2016, from https://en.wikipedia.org/wiki/Radial_artery

[12] Bos, A., Gommers, M., Jansen, A., Kalverda, O., Rouw, T. de., Smits, G., . . . Westra, R. (2012). *Biologie voor jou, leeropdrachtenboek 6 vwo.* 's-Hertogenbosch: Malmberg

[13] Keele, C.A., Neil, E. (1971). *Samson Wright's Applied Physiology.* Oxford: Oxford University Press

[14] BBC. (n.d.). *Maintaining body temperature.* Retrieved on 31-12-2016, from http://www.bbc.co.uk/schools/gcsebitesize/science/triple_ocr_21c/further_biology/maintaining_body_temperature/revision/3/

1.2.4 Capillaries

The arteries* branch out into capillaries* where the blood pressure is further decreased. A heartbeat is no longer noticeable. The walls of capillaries* consist of only one cell layer. This makes it possible for nutrients and oxygen to leave the blood and enter the tissue to reach the cells, providing them with the nutrients they need to function. Carbon dioxide and other waste products of the cells can enter the blood.[15] Transport happens via diffusion and can be transcellular and paracellular. Transcellular transport is the transport of bigger molecules like proteins through the cells of the capillary* wall. Paracellular transport is the transport of smaller molecules like gases through small gaps between the cells.[16] The more active a tissue or organ is, the more oxygen it needs to function, the more capillaries* are required. The blood enters the capillaries* oxygenated and leaves them poor in oxygen.[17]

1.2.5 Venules and veins

The capillaries* come together into venules*. Venules* have thinner walls than arterioles*, which renders the transport of fluids, nutrients and blood cells possible. Many venules* unite in veins*.[18] The function of the veins* is opposite to that of the arteries*: they guide the oxygen-poor blood back to the heart. The walls of the veins* are thinner and less elastic than the walls of arteries*, because they do not have to withstand a high and pulsating blood pressure. The blood pressure in the veins* is even lower than in the capillaries* and no heartbeat is noticeable. They lie less deep in the body than arteries* and are often visible through the skin as blue lines.[19] Before the blood from the veins* enters the heart, the veins* unite in two big veins, the venae cavae*. The blood pressure in the venae cavae* is nearly zero and they are connected to the right atrium* of the heart.[20] In figure 2 the described blood vessels and their corresponding blood pressure can be seen.[21]

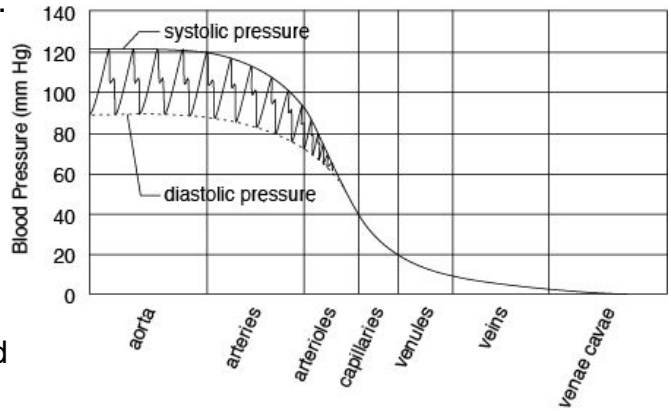

Figure 2: blood pressure decrease

[15] Bos, A., Gommers, M., Jansen, A., Kalverda, O., Rouw, T. de., Smits, G., . . . Westra, R. (2012). *Biologie voor jou, leeropdrachtenboek 6 vwo.* 's-Hertogenbosch: Malmberg

[16] Wikipedia. (29-01-2017). *Capillary.* Retrieved on 30-01-2017, from https://en.wikipedia.org/wiki/Capillary

[17] Wikipedia. (07-11-2016). *Capillary.* Retrieved on 31-12-2016, from https://en.wikipedia.org/wiki/Capillary

[18] Wikipedia. (21-11-2015). *Venules*. Retrieved on 30-01-2017, from https://en.wikipedia.org/wiki/Venule

[19] Bos, A., Gommers, M., Jansen, A., Kalverda, O., Rouw, T. de., Smits, G., . . . Westra, R. (2012). *Biologie voor jou, leeropdrachtenboek 6 vwo.* 's-Hertogenbosch: Malmberg

[20] Wikipedia. (25-07-2016). *Venae Cavae*. Retrieved on 30-01-2017, from https://en.wikipedia.org/wiki/Venae_cavae

[21] Cliffsnotes. (n.d.). *Blood Pressure.* Retrieved on 02-1-2017, from https://www.cliffsnotes.com/study-guides/anatomy-and-physiology/the-cardiovascular-system/blood-pressure

2 Types of fat and their function

2.1 Fats in general

Fat enters the body through food. Although many people see fat as something to quickly lose, the body needs it to function. Fat is used as a source of energy and as storage of energy. Fat is actually the most energy-dense nutritional substance in our bodies with 37 kJ/g compared to 17 kJ/g for both carbohydrates and proteins.[22] Fat is also necessary for quick transmittance of nerve impulses*, since the myelin sheaths* around axons* of nerve cells consist of fat.[23] Moreover, vitamins A, D, E and K rely on fat for absorption and storage.[24] Out of the thirteen vitamins, these four are known as the fat-soluble vitamins. Vitamin A is known for helping the eyes adjust to light changes and vitamin D is commonly known for helping to build stronger bones. Vitamin E protects other vitamins, red blood cells and important fats from destruction and vitamin K plays a major role in blood clotting*.[25] Another function of fat is isolating the body against cold. Animals like whales have a layer of fat cells, known as adipose tissue*. Other functions of this tissue are discussed in chapter 3. This adipose tissue* has a relatively low thermal conductivity*, which means that heat transfer between the body and the air or water is largely blocked.[26] This helps keep bodies at the correct temperature. Other stored fats surround vital organs like the heart, protecting them against sudden movements and outside impacts.[27]

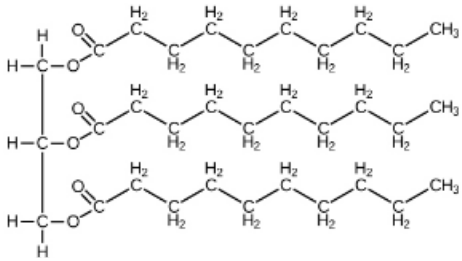

Figure 3: triglyceride

The molecules of fat are composed of three fatty acid* molecules connected to a glycerol molecule. They are called triglycerides*. The fatty acid* molecule is a long chain of carbon atoms with two hydrogen atoms bonded to them. At the very end of the chain a carboxyl group is attached.[28] Figure 3 [29] is a visual representation of a fat molecule.

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[22] New Zealand Nutrition Foundation. (n.d.). *Energy*. Retrieved on 13-11-2016, from http://www.nutritionfoundation.org.nz/nutrition-facts/Nutrients/energy

[23] Bos, A., Gommers, M., Jansen, A., Kalverda, O., Rouw, T. de., Smits, G., . . . Westra, R. (2012). *voor jou, leeropdrachtenboek 5b vwo.* 's-Hertogenbosch: Malmberg

[24] SFGate. (n.d.). *Three Functions of Fat in the Body.* Retrieved on 13-11-2016, from http://healthyeating.sfgate.com/three-functions-fat-body-3402.html

[25] Bellows. R., Moore, R. (2012, november). *Fat-Soluble Vitamins: A, D, E, and K*. Retrieved on 13-11-2016,from http://extension.colostate.edu/topic-areas/nutrition-food-safety-health/fat-soluble-vitamins-a-d-e-and-k-9-315/

[26] Science Buddies. (29-11-2011). *How Animals Stay Warm with Blubber.* Retrieved on 13-11-2016, from https://www.scientificamerican.com/article/bring-science-home-animals-stay-warm-with-blubber/

[27] ASKDrSEARS. (n.d.). *Why You Need Fats.* Retrieved on 10-10-2016, from http://www.askdrsears.com/topics/feeding-eating/family-nutrition/facts-about-fats/why-you-need-fats

[28] Wissman, P. (n.d.). *Lipids: Fats, Oils, Waxes, etc.* Retrieved on 11-10-2016, from http://homepage.smc.edu/wissmann_paul/humanbiology/lipids.html

[29] Biochemistry3rst. (2014, march) *Reflection 8 –Lipids 1.* Retrieved on 14-12-2016, from https://biochemistry3rst.wordpress.com/2014/03/24/reflection-8-lipids-1/

There are multiple types of fat, all of which have a slightly different molecular arrangement. These types are saturated fats* and unsaturated fats*. From unsaturated fats*, cis* and trans* fats can be distinguished.[30]

2.2 Saturated fats

Figure 3 shows a saturated fat*. This means that all carbon atoms have the maximum number of two hydrogen atoms attached. Therefore they are saturated.[31] Due to their chemical construction, they are mostly solid at room temperature. The carbon chains are fairly straight, making it possible to pack molecules fairly close together, resulting in stronger intermolecular bonds*. This causes the fat to be a solid at room temperature.[32] Saturated fats* can be found in animal products, such as meat and butter.

During the 1960's numerous studies found evidence that saturated fats* contribute to the risk of cancers and cardiovascular disease* like coronary artery disease*, which is further discussed in chapter 7. Even today, almost all health associations, like the World Health Organization, recommend to limit the consumption of these fats.[33] A high intake of saturated fats* is said to increase levels of LDL-cholesterol*, of which the effects will be discussed in chapter 4.[34]

2.3 Mono- and polyunsaturated fats

In figure 4 the middle carbon chain is unsaturated. There is a double bond* between two carbon atoms, which means that some room is available for hydrogen. This is why the fat is called an unsaturated fat*. Natural unsaturated fats* are configured the cis* way. This means that the two parts of the chain are located on the same side of the double bond*.[35] The middle carbon chain in figure 4 is configured the cis* way.This particular chain has one double bond* and is called a mono-unsaturated fat*. It is also possible that the chain has multiple double bonds*, which would be a polyunsaturated fat*.

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[30] Diffen.com. (n.d.). *Saturated Fats vs. Unsaturated Fats.* Retrieved on 11-10-2016, from http://www.diffen.com/difference/Saturated_Fats_vs_Unsaturated_Fats

[31] Wissman, P. (n.d.). *Lipids: Fats, Oils, Waxes, etc.* Retrieved on 11-10-2016, from http://homepage.smc.edu/wissmann_paul/humanbiology/lipids.html

[32] Villazon, L. (10-10-2009). *Why are animal fats solid yet vegetable oils liquid at room temperature?* Retrieved 15-10-2016, from http://www.sciencefocus.com/qa/why-are-animal-fats-solid-yet-vegetable-oils-liquid-room-temperature

[33] Diffen.com. (n.d.). *Saturated Fats vs. Unsaturated Fats.* Retrieved on 11-10-2016, from http://www.diffen.com/difference/Saturated_Fats_vs_Unsaturated_Fats

[34] Ophardt, C.E. (2003). *Hydrogenation of Unsaturated Fats Trans Fat.* Retrieved on 11-10-2016, from http://chemistry.elmhurst.edu/vchembook/558hydrogenation.html

[35] Wissman, P. (n.d.). *Lipids: Fats, Oils, Waxes, etc.* Retrieved on 11-10-2016, from http://homepage.smc.edu/wissmann_paul/humanbiology/lipids.html

Unsaturated fats* can be found in vegetable oils.[36] They are liquid at room temperature due to the kink in the carbon chains, which prevents molecules from packing together. This results in weaker intermolecular bonds*, enabling the molecules to easily move. This easy movement results in a liquid substance at room temperature.[37]

Two of the most important polyunsaturated fats* are omega-3 and omega-6.[38] The difference between the two is the location of the first double bond*. In omega-3 fatty acids*, the first double bond* occurs after the third carbon atom, counting from the end of the chain. Omega-6 has the first double bond* after the sixth carbon atom.[39] Both are important components of cell membranes* and omega-3 acids are thought to protect against heart disease by preventing blood clotting* in blood vessels.[40] The body is able to produce all types of fatty acids*, except for an omega-3 and an omega-6 fatty acid*. These have to be present in the diet. Foods containing these omega-3 acids are flax, salmon and broccoli. The omega-6 acids are found in nuts, whole grain bread and in most vegetable oils.[41]

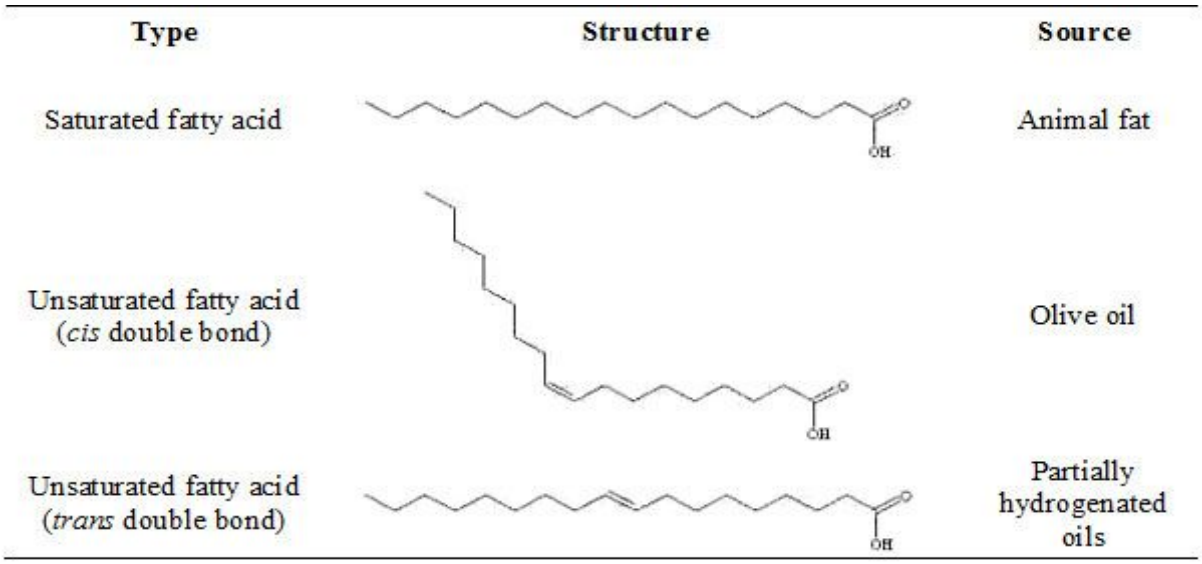

Figure 4: types of fatty acids[42]

[36] Diffen.com. (n.d.). *Saturated Fats vs. Unsaturated Fats.* Retrieved on 11-10-2016, from http://www.diffen.com/difference/Saturated_Fats_vs_Unsaturated_Fats
[37] Villazon, L. (10-10-2009). *Why are animal fats solid yet vegetable oils liquid at room temperature?* Retrieved 15-10-2016, from http://www.sciencefocus.com/qa/why-are-animal-fats-solid-yet-vegetable-oils-liquid-room-temperature
[38] Harvard University. (n.d.). *Omega-3 Fatty Acids: An Essential Contribution.* Retrieved on 11-10-2016 from https://www.hsph.harvard.edu/nutritionsource/omega-3-fats/
[39] European Food Information Council. (2008, december). *The importance of omega-3 and omega-6 fatty acids.* Retrieved on 11-10-2016, from http://www.eufic.org/article/en/artid/the-importance-of-omega-3-and-omega-6-fatty-acids/
[40] Harvard University. (n.d.). *Omega-3 Fatty Acids: An Essential Contribution.* Retrieved on 11-10-2016 from https://www.hsph.harvard.edu/nutritionsource/omega-3-fats/
[41] Diffen.com. (n.d.). *Saturated Fats vs. Unsaturated Fats.* Retrieved on 11-10-2016, from http://www.diffen.com/difference/Saturated_Fats_vs_Unsaturated_Fats
[42] Norris, S. (21-06-2007). *Trans Fats: The Health Burden.* Retrieved on 15-10-2016, from

2.4 Trans fats

During the 1950s and 1960s people became increasingly aware of the dangers of saturated animal fats in butter and other dairy products regarding an increased LDL-cholesterol* level. Scientists figured that making the healthier, unsaturated fats* from plants into a solid for butter would decrease the cases of cardiovascular disease*. They came up with a process called partial hydrogenation* to make margarine. In this process the double bonds* of the liquid unsaturated fats* are opened and hydrogen atoms are added, making some of the unsaturated fat* molecules saturated. If enough molecules are changed, then the state at room temperature will be solid instead of liquid. The margarine created this way would contain far less saturated fat* molecules than normal butter and would therefore be healthier.[43]

However, during partial hydrogenation* some of the double bonds* are turned around. They now have a trans configuration*, meaning that the two hydrogen atoms are on opposite sides of the double bond*. As a result, the carbon chain becomes more linear, like a saturated fat*.[44] A trans configurated fatty acid* can be seen in figure 4. In fact, most of the trans* fats that are created during partial hydrogenation* are classified in the same category as saturated fats*. Trans* fats also have nearly the same properties as saturated fats*. They are solid at room temperature, which is needed for making butter. On the other hand, trans* fats also adopt the negative property of raising LDL-cholesterol* levels, although not as much as saturated fats*. However, trans* fats also decrease your HDL levels.[45] The effects of this will be discussed in chapter 5.

Trans* fats are still present in many foods. A few examples are doughnuts, cookies, pies and cakes. They are used to fabricate food because they are inexpensive to produce and easy to use. Oil with trans* fats can be used multiple times in fryers.[46] It is nearly impossible to completely avoid eating trans* fats, but regulating the amount of fried food and other snacks one eats is often advised for maintaining a healthy cholesterol* level, more of which is explained in chapter 8.[47]

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http://www.lop.parl.gc.ca/content/lop/ResearchPublications/prb0521-e.htm

[43] Ophardt, C.E. (2003). *Hydrogenation of Unsaturated Fats Trans Fat.* Retrieved on 11-10-2016, from http://chemistry.elmhurst.edu/vchembook/558hydrogenation.html

[44] Wissman, P. (n.d.). *Lipids: Fats, Oils, Waxes, etc.* Retrieved on 11-10-2016, from http://homepage.smc.edu/wissmann_paul/humanbiology/lipids.html

[45] Ophardt, C.E. (2003). *Hydrogenation of Unsaturated Fats Trans Fat.* Retrieved on 11-10-2016, from http://chemistry.elmhurst.edu/vchembook/558hydrogenation.html

[46] American Heart Association. (07-10-2015). *Trans Fats.* Retrieved on 11-10-2016, from http://www.heart.org/HEARTORG/HealthyLiving/HealthyEating/Nutrition/Trans-Fats_UCM_301120_Article.jsp#

[47] Norris, S. (21-06-2007). *Trans Fats: The Health Burden.* Retrieved on 15-10-2016, from http://www.lop.parl.gc.ca/content/lop/ResearchPublications/prb0521-e.htm

2.4.1 Replacing trans fats

The food industry has sought for replacements for trans* fats since 2000. This is because many governments started implementing regulations that would render it unprofitable for the industry to keep using trans* fats. Also, public demand plays a role in the gradual stepping away from trans* fats.[48]

Some good alternatives to trans* fats for the companies to use are already being used, one of them being the interesterified fats*. These are fats built by combining three fatty acids* from multiple triglycerides* to a single triglyceride*.[49] The molecular formulas can be seen in figure 5. They were developed during the first half of the 20th century, but only recently started being used as a replacement for trans* fats.[50]

Public health concerns regarding the use of interesterified fats* have also appeared. However, virtually no experiments have been conducted to determine what the possible health risks of these fats are, compared to trans* fats. One study from 2007 found that the interesterified fats* reduced levels of HDL-cholesterol, which has negative effects discussed in chapter 5. They also depressed insulin production and raised blood glucose levels by 20 percent after four weeks.[51] Because this is only one study and it was done using just thirty test subjects, the American Heart Association decided that there was not yet enough evidence that these fats have negative impacts on one's health and that more research should be conducted.

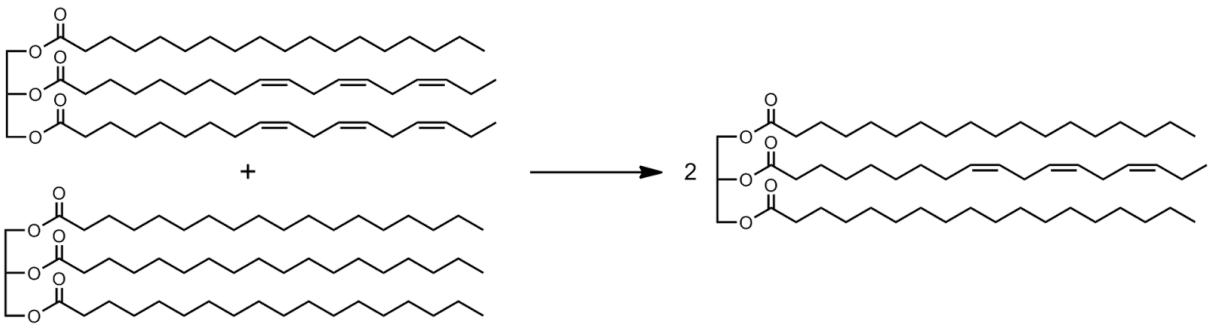

Figure 5: process of making interesterified fat[52]

[48] Diffen.com. (n.d.). *Saturated Fats vs. Unsaturated Fats.* Retrieved on 14-12-2016, from http://www.diffen.com/difference/Saturated_Fats_vs_Unsaturated_Fats

[49] Wikipedia.com. (18-11-2016). *Interesterified fat.* Retrieved 14-12-2016, from https://en.wikipedia.org/wiki/Interesterified_fat

[50] Weil, A. (08-04-2010). *Is Interesterified Oil a Bad Fat?* Retrieved 14-12-2016, from http://www.drweil.com/diet-nutrition/nutrition/is-interesterified-oil-a-bad-fat/

[51] Dr. Mercola. (05-03-2009). *Interesterified Fat--Is it Worse Than Trans Fat?* Retrieved 14-12-2016, from http://articles.mercola.com/sites/articles/archive/2009/03/05/Interesterified-Fat--Is-it-Worse-Than-Trans-Fat.aspx

[52] Wikipedia.com. (18-11-2016). *Interesterified fat.* Retrieved 14-12-2016, from https://en.wikipedia.org/wiki/Interesterified_fat

3 From food to fat

3.1 Energy

Every living organism needs energy to function. Energy is amongst others used to move, to breathe, to process food, to renew cells. Some organisms are autotrophic*. These organisms are able to produce their own energy, for example plants. Through photosynthesis*, plants are able to convert light into glucose. Because they use light to make their energy, they are called phototrophic*.[53] Another type of autotrophic* organisms are the chemotrophic* organisms, which use chemical substances to produce their energy. Thiobacilli, a type of sulphurbacteria are an example of this. They release energy converting sulphur in the chemical equation:

$$S^{2-} + 2\ O_2 \rightarrow SO_4^{2-} + \text{energy}$$[54]

Humans however are heterotrophic* organisms. These organisms cannot provide their own energy, which means they must consume other organisms to obtain their energy. These organisms can be autotrophic* or heterotrophic*. Vegetables and rice for example are autotrophic*, whereas a piece of meat is a part of a heterotrophic* organism.

3.2 Digestive system

When humans consume food, it must be broken down to enable the body to absorb the nutrients in the food. This happens in the digestive system*. The digestive system* consists of a series of organs that each have a function in digestion.

3.2.1 Mouth

Food enters the body via the mouth, where teeth, the tongue and salivary glands work together to begin digestion. The teeth cut the food into smaller pieces to make it easier to swallow and to enlarge the surface area of the food. A larger surface area enables the gastric acid in the stomach to work quicker and more efficiently. The tongue is covered in taste buds which give humans the sense of taste. The muscles in the tongue push the food backwards for swallowing. The salivary glands produce a watery substance which moistens the food to make it swallowable. It also contains several enzymes* which start digestion.[55]

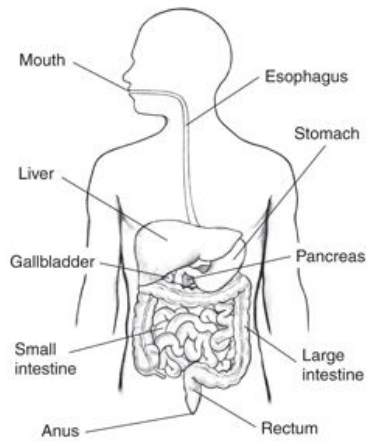

Figure 6: digestive system [56]

[53] Bos, A., Gommers, M., Jansen, A., Kalverda, O., Rouw, T. de., Smits, G., . . . Westra, R. (2012). *Biologie voor jou, leeropdrachtenboek 6 vwo.* 's-Hertogenbosch: Malmberg

[54] Bouwens, R.E.A., Groot, P.A.M de, Kranendonk, W., Lune, J.P. van, Prop - van den Berg, C.M., Riswick, J.A.M.H. van, Westra, J.J. (2013). *Binas havo/vwo, table 69D.* Groningen/Houten: Noordhoff Uitgevers

[55] Taylor, T. (n.d.). *Digestive system.* Retrieved on 11-10-2016, from http://www.innerbody.com/image/digeov.html

3.2.2 Stomach

After swallowing, the chewed food passes through the throat and esophagus* into the stomach. At the end of the esophagus* is a muscular ring to prevent the food from going back. The stomach is a muscular sack used for storage of food and further digestion. On average, it is as big as two fists. The stomach is a very acidic environment with a pH* between 1.2 and 3.0.[57] This kills bacteria that may have entered the body with food. A layer of slime protects the wall of the stomach against the acidity, since the high acidity can damage cells. A meal stays on average 3 to 5 hours[58] in the stomach. Another muscular ring at the end of the stomach, called the pylorus*, prevents the food from moving on to the small intestine*. Every now and then the pylorus* relaxes and a small amount passes through.[59]

3.2.3 Intestines

When leaving the stomach, the food enters the small intestine*. The first part of the small intestine* is the duodenum*. The digestive juices from the pancreas* and liver are added here. The pancreas* secretes digestive enzymes*. The liver makes bile*, which consists of water, bile salts and pigments. The pigments are the cause of the brown colour in excrement.[60] The bile salts work as an emulsifier* for fats. Fats are hydrophobic*, therefore they do not mix with water and form big droplets. The bile salts divide the big droplets into smaller ones and form micelles*. As a result, the fats are dissolved. Also, the surface area is increased which makes further digestion easier.[61]

The small intestine* is a thin tube that is about 7 metres long. It is coiled to fit in the body. The inside has many ridges and folds, which results in a large surface area. This maximizes the digestion of food and absorption of nutrients. The large intestine* is a thicker tube that is about 1.5 metres long. The remains of the food that cannot be digested any further end up here. The large intestine* removes the water, which thickens the waste. The waste exits the body via the anal canal.[62]

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[56] National Institue of Diabetes and Digestive and Kidney Diseases (09-2013). *Your digestive system and how it works.* Retrieved on 15-10-2016, from https://www.niddk.nih.gov/health-information/health-topics/Anatomy/your-digestive-system/Pages/anatomy.aspx

[57] Serkozy. (09-03-2016). *Wat is de pH-waarde?.* Retrieved on 11-10-2016, from http://mens-en-gezondheid.infonu.nl/leven/52312-wat-is-de-ph-waarde.html

[58] Bowen, R. (27-05-2006). *Gastrointestinal Transit: How Long Does It Take?.* Retrieved on 11-10-2016, from http://www.vivo.colostate.edu/hbooks/pathphys/digestion/basics/transit.html

[59] Bos, A., Gommers, M., Jansen, A., Kalverda, O., Rouw, T. de., Smits, G., . . . Westra, R. (2012). *Biologie voor jou, leeropdrachtenboek 6 vwo.* 's-Hertogenbosch: Malmberg

[60] Bos, A., Gommers, M., Jansen, A., Kalverda, O., Rouw, T. de., Smits, G., . . . Westra, R. (2012). *Biologie voor jou, leeropdrachtenboek 6 vwo.* 's-Hertogenbosch: Malmberg

[61] University of Washington (n.d.). *Digestion and absorption of fats.* Retrieved on 11-10-2016, from https://courses.washington.edu/conj/bess/fats/fats.html

[62] Taylor, T. (n.d.). *Digestive system.* Retrieved on 11-10-2016, from http://www.innerbody.com/image/digeov.html

3.2.4 Digestion of fat

Fats in our diet are triglycerides*, which cannot be absorbed directly since they are too big to pass through the cell membranes*. Therefore must be broken down. First, the bile salts work as emulsifier* and form micelles* as discussed in the previous paragraph. The fat must be emulsified because the enzyme* lipase is hydrophilic* and can therefore only work in an aqueous environment. Lipase forms a complex with the co-enzyme* colipase.[63] Lipase splices triglycerides* into fatty acids*, mono- and diglycerides. Together with the bile salts and other fat soluble nutrients, for example vitamin A and cholesterol*, they form micelles*. Everything except for the bile salts enters the lymphatic system*, which later merges with the blood circuit. Extraordinary in comparison to other nutrients is that fat soluble nutrients in the micelles* do not pass through the liver and thus are directly discharged into the bloodstream. The reason for this is unknown.

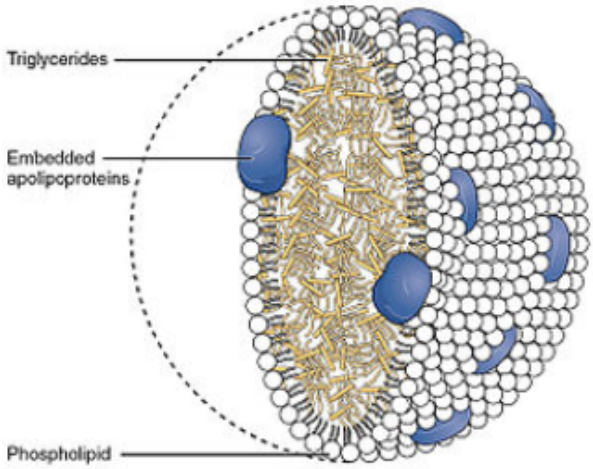

Figure 7: chylomicron[64]

The fat soluble nutrients are transported to the cells, where they are used to build membranes. This is done by chylomicrons*. Chylomicrons* are lipoprotein* particles consisting of triglycerides*, phospholipids*, cholesterol* and proteins.[65] They are also the source of the milky appearance of blood plasma* after eating fat. When the nutrients are not immediately used, the chylomicrons* are partially digested into free fatty acids*, glycerol and chylomicron* residue. The liver removes the glycerol and chylomicron* residue from the blood circulation. The free fatty acids* are resynthesized into triglycerides* and stored. An excess of glucose can also be transformed into fat and be stored in the same way. [66] [67]

[63] Wikipedia (24-05-2016). *Colipase.* Retrieved on 11-10-2016, from https://en.wikipedia.org/wiki/Colipase
[64] Wikipedia (12-09-2016). *Chylomicron.* Retrieved on 11-10-2016, from https://en.wikipedia.org/wiki/Chylomicron
[65] Wikipedia (12-09-2016). *Chylomicron.* Retrieved on 11-10-2016, from https://en.wikipedia.org/wiki/Chylomicron
[66] Wikipedia (25-01-2016). *Fatty acid metabolism.* Retrieved on 11-10-2016, from https://en.wikipedia.org/wiki/Fatty_acid_metabolism#Dietary_sources_of_fatty_acids.2C_their_digestion
[67] Freudenrich, Craig, PH.D. (w.d). *How fat cells work*.Retrieved on 15-10-2016, from http://science.howstuffworks.com/life/cellular-microscopic/fat-cell1.htm

Fat molecules are resynthesized after they are broken down. The actions seem useless, but are necessary. Fat molecules are too large to pass through cell membranes*, and therefore must be broken down to pass from the small intestine* into the lymphatic system*. They are resynthesized because the large fat molecules do not attract as many excess water by osmosis* in comparison to smaller molecules, and therefore are better storage material. [68]

3.3 Storage of fat

An excess of food is stored by the body for a rainy day. In case of food deprivation or malnutrition, the body can provide itself with energy by burning the stored food. The most efficient way of storing energy for humans is by storing it as fat, also known as adipose tissue*. There are two types of adipose tissue*: brown adipose tissue and white adipose tissue. [69]

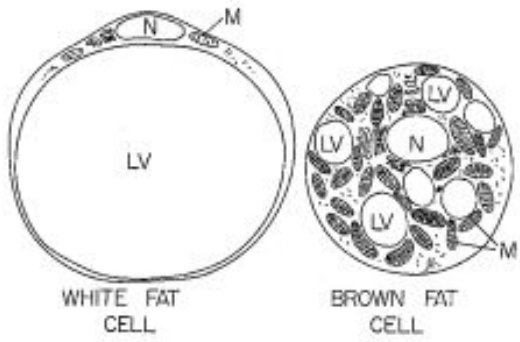

Figure 8: adipose tissue cells[70]

3.3.1 Brown adipose tissue

Brown adipose tissue transfers energy from food into heat. It consist of many small droplets of fat and many mitochondria* (M in figure 8). A mitochondrion* is the powerhouse of the cell. It is able to turn glucose into energy, in this case heat energy. The tissue also contains many blood vessels, which enables the distribution of heat through the body. The tissue is activated when an organism needs extra heat, particularly after hibernating or in the first months of its life. This is also the reason why it is primarily found in infants and hibernating animals. Brown adipose tissue is often referred to as “good” fat, since it burns calories by creating heat.[71][72]

[68] Freudenrich, Craig, PH.D. (w.d). *How fat cells work*.Retrieved on 15-10-2016, from http://science.howstuffworks.com/life/cellular-microscopic/fat-cell1.htm
[69] Wikipedia (09-01-2016). *Adipose tissue*. Retrieved on 13-11-2016, from https://en.wikipedia.org/wiki/Fatty_acid_metabolism#Dietary_sources_of_fatty_acids.2C_their_digestion.2C_absorption.2C_transport_in_the_blood_and_storage
[70] Albright, A.L., Stern, J.S. (1998). *Adipose tissue.* Retrieved on 13-11-2016, from http://www.sportsci.org/encyc/adipose/adipose.html
[71] Cannon, B., Nedergaard, J. (01-2004). *Brown adipose tissue: function and physiological significance.* Retrieved on 13-11-2016, from https://www.ncbi.nlm.nih.gov/pubmed/14715917
[72] Freudenrich, Craig, PH.D. (w.d). *How fat cells work*.Retrieved on 13-11-2016, from http://science.howstuffworks.com/life/cellular-microscopic/fat-cell1.htm

3.3.2 White adipose tissue

White adipose tissue however, is often called “bad” fat. It is the type of fat middle-aged women usually complain about. White adipose tissue contains significantly fewer mitochondria* than brown adipose tissue. This suits the function of the tissue, as it contains cells that store excess fat. The individual cells in white adipose tissue are also larger. The reason for this is that the number of fat cells in this type of tissue does not change after adolescence, whereas the size does. White fat cells can shrink or expand, due to an excess or lack of energy.[73] If the intake of calories is more than the energy usage, energy will be stored and therefore fat cells will expand. The other way around, if an individual burns more calories than eaten, the fat storage will fill the energy-gap and white fat cells will shrink.[74]
Storage of fat is not the only function of white adipose tissue. Other functions are the secretion of hormones* and protection of abdominal* organs. [75]

[73] Live Strong (10-07-2015). *How Is Fat Stored and Burned as Energy in the Human Body?.* Retrieved on 13-11-2016, from http://www.livestrong.com/article/362122-how-is-fat-stored-and-burned-as-energy-in-the-human-body/
[74] Freudenrich, Craig, PH.D. (w.d). *How fat cells work*.Retrieved on 15-10-2016, from http://science.howstuffworks.com/life/cellular-microscopic/fat-cell1.htm
[75] Albright, A.L., Stern, J.S. (1998). *Adipose tissue.* Retrieved on 13-11-2016, from http://www.sportsci.org/encyc/adipose/adipose.html

4 Cholesterol

4.1 Cholesterol

Cholesterol* is a fatlike substance that can be found in most of the cells in animals. The body uses it to make important compounds of the cell membranes*. Cholesterol* makes up 30% of the compounds in animal cell membranes*. It gives the animal cell its stability, while also maintaining its flexibility. This contributes to animal cells not needing cell walls*. Cholesterol* is also used by the human body to make hormones* and fat soluble vitamins like vitamin A, D, E and K, which have been discussed in chapter 2.[76] Cholesterol* is a hydrophobic* molecule. It can therefore not be dissolved in the blood plasma* in great quantities, since the blood plasma* is hydrophilic*. This would mean that it is nearly impossible to transport it from one place to another in the body, because the hydrophobic* cholesterol* molecules that don't dissolve into the blood will stick to the wall of the blood vessels. This can turn into plaque* with mechanisms that will be discussed in chapter 5. The negative effects of plaque* will be discussed in chapter 7. This is why the body uses lipoproteins* to carry the cholesterol* through the body.[77]

4.2 Lipoproteins

These lipoproteins* have a spherical structure with a phospholipid* layer on the inside and a layer of proteins on the outside. The layer of phospholipids* is hydrophobic*, so the cholesterol* molecules stay in the lipoprotein*, since they are also hydrophobic*. The proteins on the outside make the lipoprotein* dissolvable in the blood, because these proteins are hydrophilic*. There are five different types of lipoproteins*. High-density, low-density, intermediate-density, very-low-density and ultra-low-density lipoproteins*. The latter is more commonly known as chylomicrons*.[78]

4.3 Lipoprotein metabolism

The lipoprotein* particle metabolism* can be divided into three pathways. The first is the exogenous* pathway. As discussed in chapter 2.2.4, fat that is digested will travel through the body by chylomicrons*. They carry the fat soluble nutrients through the lymphatic system* and the blood. The fat that is not used in membranes immediately is carried to the liver by chylomicrons*. The second pathway of the lipoprotein* metabolism* is the endogenous* pathway.[79]

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[76] Wikipedia.com. (16-01-2017). *Cholesterol*. Retrieved on 11-10-2016, from https://en.wikipedia.org/wiki/Cholesterol#cite_note-isbn1-4292-4646-4-14

[77] American Heart Association. (21-04-2014). *Good vs. Bad Cholesterol*. Retrieved on 10-10-2016, from http://www.heart.org/HEARTORG/Conditions/Cholesterol/AboutCholesterol/Good-vs-Bad-Cholesterol_UCM_305561_Article.jsp#.WI9sk_nhCM9

[78] University of Washington. (n.d.). *Lipoproteins.* Retrieved on 30-01-2017, from http://courses.washington.edu/conj/membrane/lipoprotein.htm

[79] Kingsbury, K. J., Bondy, G. (n.d.) *Understanding the Essentials of Blood Lipid Metabolism*. Retrieved on 30-01-2017, from http://www.medscape.com/viewarticle/451762_5

The cholesterol* that was carried to the liver with the other fat soluble nutrients is transported from the liver to the rest of the body by the other lipoproteins*. Very-low-density lipoproteins*, or VLDL, is synthesized by the liver. As VLDL moves through the body it loses some of the molecules that make up the spherical structure and changes into intermediate-density lipoproteins which in turn change into low-density lipoproteins* or LDL*. Lastly, lipoproteins* are needed for reverse cholesterol* transport. High-density lipoproteins* or HDL* gathers the cholesterol* throughout the body and brings it to the liver, where it is secreted in bile* or converted to bile salts. The function of bile salts has been discussed in chapter 3.2[80]

4.4 Influencing HDL and LDL cholesterol

LDL* and HDL* make up most of the cholesterol* in the body. They play different roles in the lipoprotein* particle metabolism* and therefore have different effects on the body. Both LDL* and HDL* carry the same amount of cholesterol* and therefore have the same weight. This causes LDL* to be bigger than HDL*, since LDL* has a lower density. LDL* is commonly known as bad cholesterol* and HDL* is commonly known as good cholesterol*. This will be discussed further in chapter 5.1.

4.4.1 The influences of a fatty diet

The amount of LDL* and HDL* in a body is partly determined by one's diet. The more fat digested, the more LDL* and HDL* needed to transport that fat through the body. Cholesterol* is measured in the levels of HDL*, LDL* and triglycerides* in the blood. In a study performed in 1990 researchers found that different diets contribute to the levels of LDL*, HDL* and triglycerides* in the blood. The subjects were put on three different diets. On the first diet, the only fats consumed were trans* fats. During this diet the HDL* levels dropped by about 10%, which was 0.03 to 0.17 mmol per litre depending on the original HDL* levels. Mmol per litre is a unit for chemical quantity. When a diet of eating mostly saturated fats* was followed, the overall cholesterol* level was higher than during the other diets, which was mostly caused by the rising in LDL*. The third diet consisted of fatty acids* with a cis* double bond*. During this diet the LDL* levels were lowest and the HDL* levels were average to high. This study shows that a difference in diet, or which fats one eats, can lead to a difference in the level of HDL* and LDL* in the blood.[81]

[80] University of Washington. (n.d.). *Cholesterol, Lipoproteins and the Liver.* Retrieved on 18-11-2016, from http://courses.washington.edu/conj/bess/cholesterol/liver.html

[81] NEJM. (16-08-1990). *Effect of Dietary trans Fatty Acids on High-Density and Low-Density Lipoprotein Cholesterol Levels in Healthy Subjects.* Retrieved on 11-10-2016, from http://www.nejm.org/doi/full/10.1056/NEJM199008163230703#t=article

4.4.2 Other influences

The diets are not the only factors that can influence the LDL* and HDL* levels in a person's blood. While it is not entirely known how these factors influence the HDL/LDL* ratio, strong correlations* have been found between these factors and the HDL/LDL* ratio.

Studies have found that a person's weight/height ratio directly relates to their HDL* levels. It has been found that the heavier one is, the less HDL* they have in their blood. Smoking has also been found to be related to lower HDL* levels. Alcohol consumption is also found to be related to higher levels of HDL* in the blood.[82] The average female has higher LDL* and HDL* levels than the average male. As one ages, the cholesterol* levels in the blood will rise.[83] Exercise is also found to increase the HDL* levels is someone's blood.[84] The remaining factors that influence the LDL* and HDL* levels in someone's blood are genetically* determined. [85] [86]

[82] Ernst, N., Fisher, M., Smith, W., Gordon, T., Rifkind, B.M., Little, J.A., Mishkel, M.A., Williams, O.D. (1980). *The association of plasma high-density lipoprotein cholesterol with dietary intake and alcohol consumption. The Lipid Research Clinics Prevalence Study.* Retrieved on 15-10-2016, from http://europepmc.org/abstract/med/7418143

[83] Volpato, S., Zuliani, G., Guralnik, J.M., Palmieri, E., Fellin, R. (2001). *The Inverse Association between Age and Cholesterol Level among Older Patients: The Role of Poor Health Status.* Retrieved on 15-10-2016, from http://www.karger.com/Article/Abstract/52768

[84] Gordon, P. M., Visich, P. S., Goss, F. L., Fowler, S., Warty, V., Denys, B. J., Metz, K. F., Robertson, J. (09-03-2007). *Comparison of Exercise and Normal Variability on HDL Cholesterol Concentrations and Lipolytic Activity.* Retrieved on 20-10-2016, from https://www.thieme-connect.com/products/ejournals/abstract/10.1055/s-2007-972856

[85] Tall, A.R. (1990). *Plasma High Density Lipoproteins.* Retrieved on 11-10-2016, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC296738/pdf/jcinvest00074-0007.pdf

[86] Glueck, CJ., Taylor, H.L., Jacobs, D., Morrison, J.A., Beaglehole, R., Williams, O.D. (1980). *Plasma high-density lipoprotein cholesterol: association with measurements of body mass. The Lipid Research Clinics Program Prevalence Study.* Retrieved on 15-10-2016, from http://europepmc.org/abstract/med/7418145

5 Atherosclerosis

5.1 The buildup of plaque

As discussed in chapter 4, LDL* is commonly known as the bad cholesterol*. This is because a fraction of LDL* deposits the cholesterol* it is carrying in the blood. HDL* will usually pick up this excess cholesterol* and transport it to the liver. This is why it is commonly known as the good cholesterol*. If the excess cholesterol* in the blood is not picked up, it can stick to the inner wall of the blood vessel. This will cause a certain type of white blood cell, the macrophage*, to try and engulf the cholesterol* molecule. Macrophages* normally clear the body from unwanted pathogens* and disappear from the body through the lymphatic system*. When a macrophage* tries to transport the cholesterol* out of the body it fails. The macrophage* absorbs the LDL-lipoproteins* and becomes filled with them, giving it a foamy appearance.[87][88] It is not understood why the macrophages* act this way.[89] They stick to the wall of the blood vessel, which causes other excesses of cholesterol* to become stuck behind this foam cell. Again a macrophage* will try to clean it up out of the blood vessel. This macrophage* will then become a foam cell and get stuck to the other foam cell. This cycle continues and a buildup of foam cells develops. As other substances found in the blood stick to these foam cells, the buildup will slowly turn into plaque*.

5.2 Atherosclerosis

The buildup of plaque* in a human blood vessels is referred to as atherosclerosis*.[90] The main cause for atherosclerosis* is a high LDL* percentage and a low HDL percentage as described in paragraph 5.1. This is more commonly referred to as a high cholesterol*. When cholesterol* is being measured, not only the LDL* and HDL* percentages are measured, but also the triglyceride* concentrations. Triglycerides* contribute to the hardening and the thickening of artery* walls. Increased levels of triglycerides*, which is on average more than 200 mg/dL[91], are are found to be related to an increase in plaque*.[92] Mg/dL is a unit for chemical quantity in a liquid.

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[87] American Heart Association. (n.d.). *Cholesterol and CAD.* Retrieved on 10-10-2016, from http://watchlearnlive.heart.org/CVML_Player.php?moduleSelect=chlcad

[88] Nature. (n.d.). *Foam Cells.* Retrieved on 23-01-2017, from http://www.nature.com/subjects/foam-cells

[89] Fog Bentzon, J., Otsuka, F., Virmani, R., Falk, E., (05-06-2016). *Mechanisms of Plaque Formation and Rupture.* Retrieved on 23-01-2017, from http://circres.ahajournals.org/content/114/12/1852

[90] NIH. (22-06-2016). *What Is Atherosclerosis?.* Retrieved on 08-01-2017, from https://www.nhlbi.nih.gov/health/health-topics/topics/atherosclerosis

[91] MFMER. (15-08-2015). *Triglycerides: Why do they matter?* Retrieved on 21-01-2017, from http://www.mayoclinic.org/diseases-conditions/high-blood-cholesterol/in-depth/triglycerides/art-20048186?pg=2

[92] AHA. (13-01-1998). *Echo-Lucency of Computerized Ultrasound Images of Carotid Atherosclerotic Plaques Are Associated With Increased Levels of Triglyceride-Rich Lipoproteins as Well as Increased Plaque Lipid Content.* Retrieved on 21-01-2017, from http://circ.ahajournals.org/content/97/1/34.short

5.3 The effects of plaque

The plaque* formed in the blood vessels will harden over time, causing serious health issues. These issues will be discussed in chapter 7. One of the effects of plaque* buildup is the rise of blood pressure.[93]

The plaque* that builds up will limit the blood flow in that blood vessel. To understand how a buildup of plaque* influences the bloodstream, an experiment will be performed. In this experiment the correlation* between the pressure in a blood vessel and the amount of plaque* obstructing the blood flow will be researched. A model will be build to represent a human blood vessel. Surrounding an obstruction of plaque*, pressure will be measured. The measurements of the pressure will be used to show how a buildup of plaque* can influence the blood pressure.

[93] medic8.com. (n.d.). *Aterioscleroses.* Retrieved on 31-01-2017, from http://www.medic8.com/healthguide/blood-pressure/arteriosclerosis.html

6 Experiment

The experiment conducted consists of measurements of pressure on equidistant points on a model of a blood vessel without obstruction and with several degrees of obstruction. The obstruction was represented by a clamp that decreased the radius of the blood vessel. A clear flexible tube was used as the blood vessel.

6.1 Material and method

- 3x 0.75 metres of flexible tube with a diametre of 5.8 mm
- 3x 0.50 metres of flexible tube with a diametre of 5.8 mm
- 12 metres of flexible tube with a minor axis of 3.3 mm and a major axis of 4.8 mm
- Hose clamp
- Nautilus 3000 pump
- 60 litre oval bucket
- 50 litres of water
- Bosch PSR 14,4 V LI-2 drill
- Wood bit size 7
- Permanent marker
- Tape measure
- Wooden board
- Nail pipe clips
- 6 pieces of rope of 25 centimetres
- Framing hammer
- Stanley knife

Six holes are drilled in the big tube with the wood bit, 10,04 m from the beginning of the tube. In figure 9 the red dots represent these holes, which are 15 cm apart. The green dot represents the place of the clamp and lies in between the third and fourth hole. The ends of the thin tubes of 50 cm and 75 cm are cut straight, perpendicular to the tube, with the stanley knife. In the red holes numbered 1, 2 and 3, one sticks the 75cm long clear tubes perpendicular to the tube. The 50 cm long clear thin tubes are placed in the other three holes, number 5, 6 and 7. At the bottom of each tube 25 cm of rope is wrapped around the the big tube and the small tubes to prevent water from leaking. Next to the six clear tubes, lines are drawn 1,0 cm apart, starting at 0,0 cm at the point where the small and big tube connect, functioning as measuring lines. The big tube is then connected to the pump's outlet. The pump is put in the bucket. The bucket is filled with water until the pump is completely submersed. This prevents air from entering the tube. In order to strengthen the model, the tubes are clamped to a wooden board with the nail pipe clips and the hammer, as seen in figure 9.

Measurements are taking after the pump is turned on. The pump is turned off. After the measurements the hose clamp is clamped on the green dot 4 of figure 9. The pump is turned on again and the water level of the six small tubes is measured. The pump is turned off.

The measurements are taken in four different positions of the arrangement of the experiment. In position one the hose clamp is not placed on the tube. In position two the hose clamp is placed on the tube in such a way that the tube's minor axis is 0.16 cm wide. In position three the hose clamp is placed on the tube in such a way that the tube's minor axis is 0.57 cm wide. In position four the hose clamp is placed on the tube in such a way that the tube's minor axis is 0.37 cm wide.

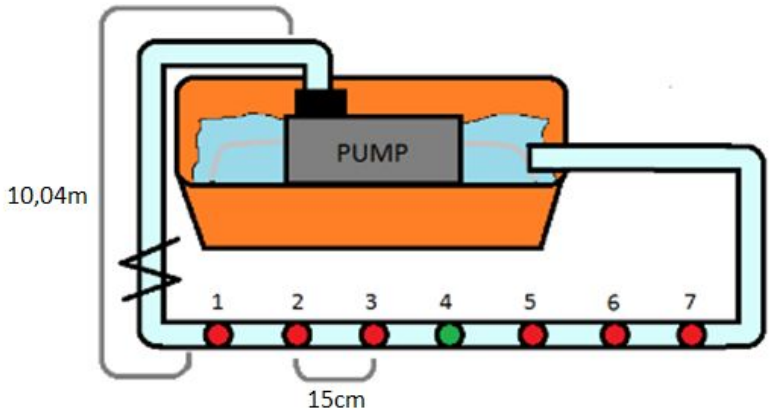

Figure 9: schematic drawing of experiment[94]

[94] Besseling, L.S. (10-2016). *Schematic drawing of experiment.* Nibbixwoud.

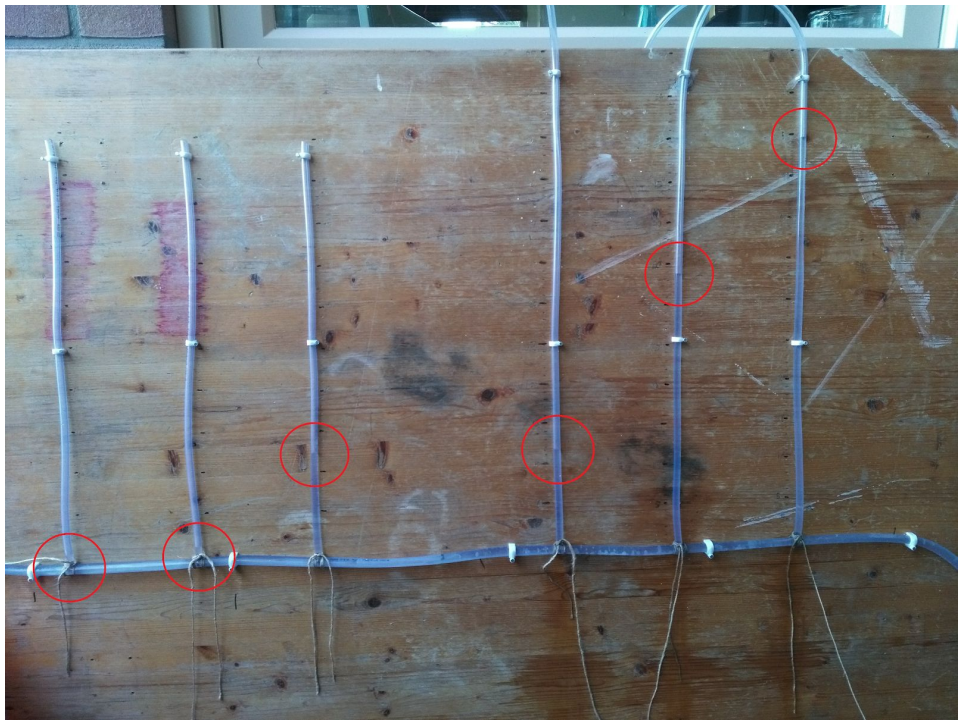

Figure 10 : water levels without narrowing

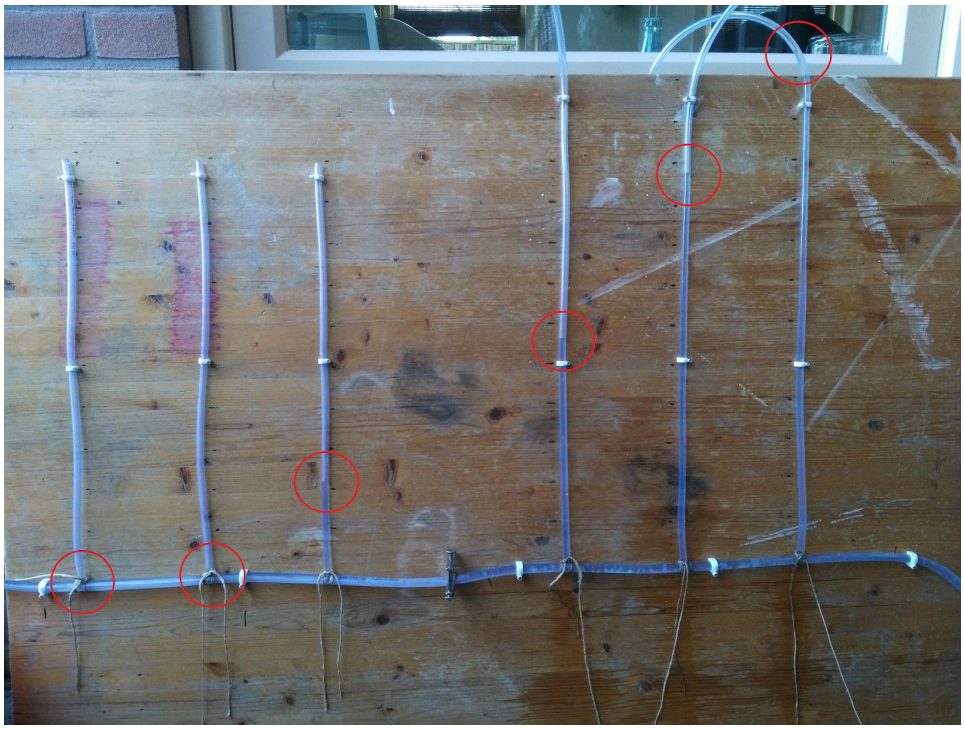

Figure 11 : water levels with narrowing

N.B.: the figures 10 and 11 are pictures taken during the building and testing of the model. The values in the pictures are therefore not similar to the values used for the results.

6.2 Results

The numbers 1 up until and including 7 correspond with the numbers in figure 9. Number 4 is where the hose clamp is placed. Therefore, no measurements could be taken at number 4. The average of the three measurements is used for graphs and calculations.

6.2.1 Equations

The following equations are used for calculations.

$p = \rho \cdot h \cdot g$ [95]

p is pressure in Pa

ρ is density in kg/m^3

h is height in m

g is gravitational acceleration in m/s^2

ρ_{water} = 0.9982 kg/m^3 [96]

$g_{Netherlands}$ = 9.81 m/s^2 [97]

$p = \frac{F}{A}$ [98] $\rightarrow F = p \cdot A$

F is force in N

p is pressure in Pa

A is area in m^2

$A_{ellipse} = \pi \cdot a \cdot b$ [99]

$A_{ellipse}$ is area in cm^2

a is the length of the semi-major axis in cm

b is the length of the semi-minor axis in cm

a = 0.49 cm

b = 0.36 cm

$A = \pi \cdot 0.49 \cdot 0.36$

A = 0.55 cm^2

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[95] Bouwens, R.E.A., Groot, P.A.M de, Kranendonk, W., Lune, J.P. van, Prop - van den Berg, C.M., Riswick, J.A.M.H. van, Westra, J.J. (2013). *Binas havo/vwo, table 35C2.* Groningen/Houten: Noordhoff Uitgevers

[96] Bouwens, R.E.A., Groot, P.A.M de, Kranendonk, W., Lune, J.P. van, Prop - van den Berg, C.M., Riswick, J.A.M.H. van, Westra, J.J. (2013). *Binas havo/vwo, table 11.* Groningen/Houten: Noordhoff Uitgevers

[97] Bouwens, R.E.A., Groot, P.A.M de, Kranendonk, W., Lune, J.P. van, Prop - van den Berg, C.M., Riswick, J.A.M.H. van, Westra, J.J. (2013). *Binas havo/vwo, table 7A.* Groningen/Houten: Noordhoff Uitgevers

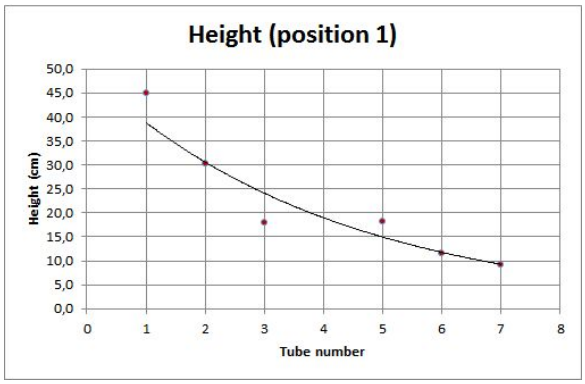
[98] Bouwens, R.E.A., Groot, P.A.M de, Kranendonk, W., Lune, J.P. van, Prop - van den Berg, C.M., Riswick, J.A.M.H. van, Westra, J.J. (2013). *Binas havo/vwo, table 35C1.* Groningen/Houten: Noordhoff Uitgevers

[99] Wikipedia (09-12-2016). *Ellipse*. Retrieved on 29-12-2016, from https://en.wikipedia.org/wiki/Ellipse#Area

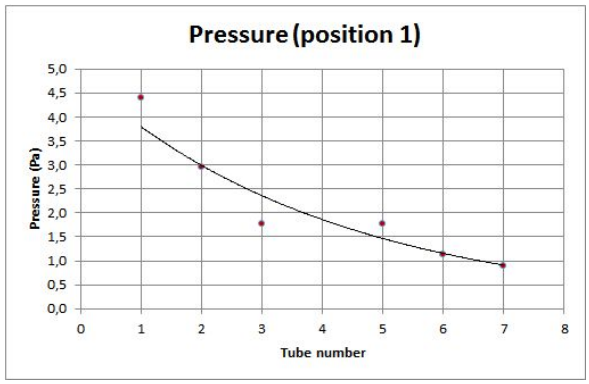
6.2.2 Tables and graphs

	Measurement 1 Height (cm)	**Measurement 2 Height (cm)**	**Measurement 3 Height (cm)**	**Average Height (cm)**	**Pressure (Pa)** $p = \rho \cdot h \cdot g$	**Force (10^{-2} N)** $F = p \cdot A$
1	45.0	44.5	45.0	44.8	4.39	2,41
2	37.0	16.5	37.0	30.2	2.95	1,62
3	18.5	17.5	18.0	18.0	1.76	0,97
4	-	-	-	-	-	-
5	18.0	18.0	18.5	18.2	1.78	0,98
6	12.5	11.0	11.0	11.5	1.13	0,62
7	9.5	9.0	9.0	9.17	0.90	0,50

Table 1: position 1



Graph 1

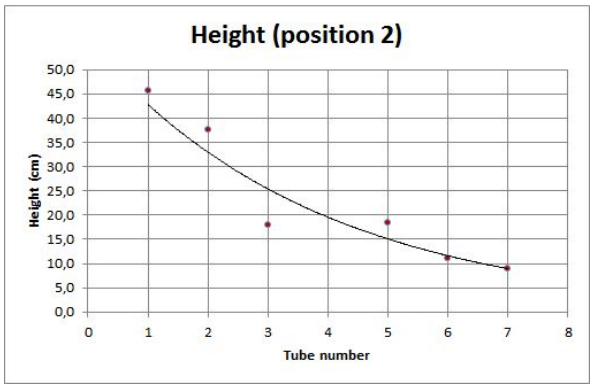


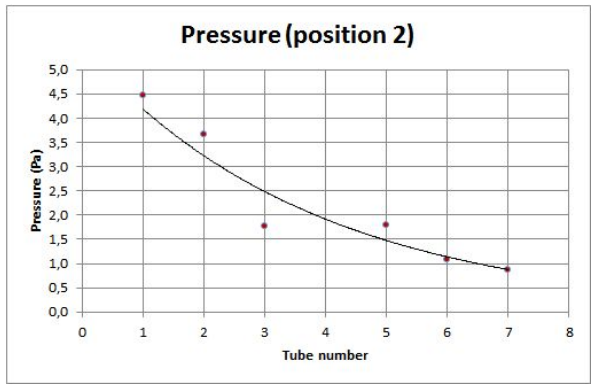
Graph 2

In table 1, the height decreases fast from 1 to 3, and decreases less fast from 5 to 7. This is visualised in graph 1. The height of number 4 could not be measured, but can be estimated following the trend line.
The height is proportional to the pressure, since the density and the gravitational acceleration are constant. Therefore only the height influences the pressure. As a result, the lines in graph 1 and graph 2 are identical.

	Measurement 1 Height (cm)	Measurement 2 Height (cm)	Measurement 3 Height (cm)	Average Height (cm)	Pressure (Pa) $p = \rho \cdot h \cdot g$	Force (10^{-2} N) $F = p \cdot A$
1	45.5	45.5	46.0	45.7	4.47	2,46
2	37.5	37.5	37.5	37.5	3.67	2,02
3	18.0	18.0	18.0	18.0	1.76	0,97
4	-	-	-	-	-	-
5	18.5	18.0	18.5	18.3	1.80	0,99
6	11.0	11.5	10.5	11.0	1.08	0,59
7	9.0	9.0	9.0	9.0	0.88	0,48

Table 2: position 2



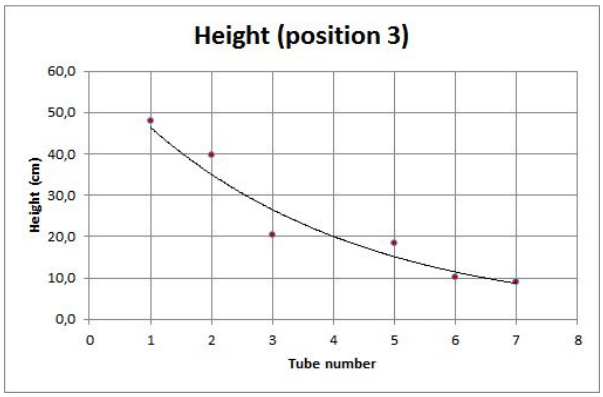


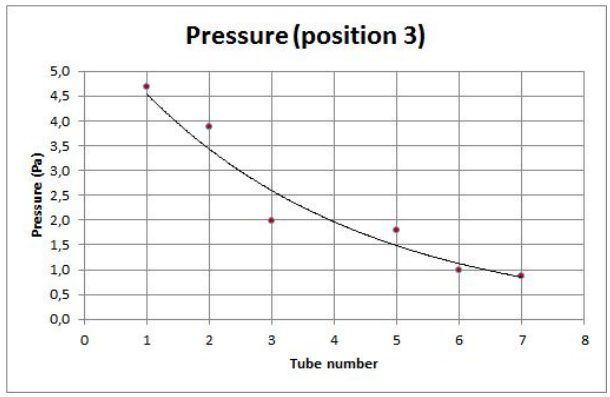
Graph 3 *Graph 4*

In table 2, the height decreases fast from 1 to 3, and decreases less fast from 5 to 7. This is visualised in graph 3. The height of number 4 can be estimated following the trend line again.
The lines in graph 3 and graph 4 are identical too.

	Measurement 1 Height (cm)	Measurement 2 Height (cm)	Measurement 3 Height (cm)	Average Height (cm)	Pressure (Pa) $p = \rho \cdot h \cdot g$	Force (10^{-2} N) $F = p \cdot A$
1	47.5	47.5	48.5	47.8	4.68	2,57
2	39.5	39.5	40.0	39.7	3.88	2,13
3	20.0	20.0	21.0	20.3	1.99	1,09
4	-	-	-	-	-	-
5	18.0	18.0	19.0	18.3	1.80	0,99
6	10.5	10.0	10.0	10.2	1.00	0,55
7	9.0	9.0	9.0	9.00	0.88	0,48

Table 3: position 3



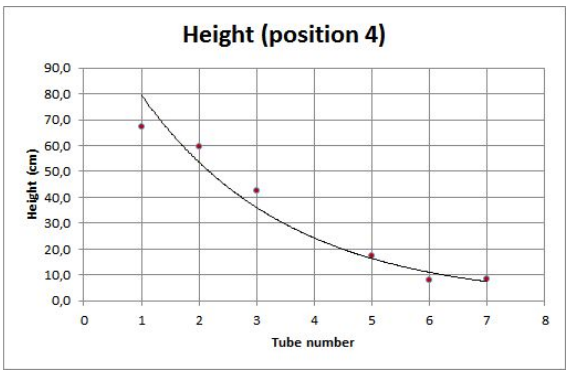


Graph 5 *Graph 6*

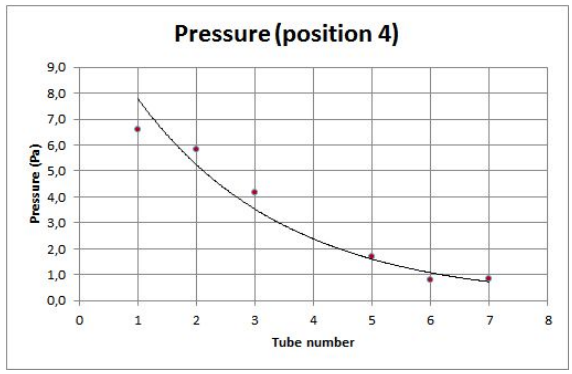
In table 3, the height decreases fast from 1 to 3, and decreases less fast from 5 to 7. This is visualised in graph 5. The height of number 4 can be estimated following the trend line again.
The lines in graph 5 and graph 6 are identical too.

	Measurement 1 Height (cm)	Measurement 2 Height (cm)	Measurement 3 Height (cm)	Average Height (cm)	Pressure (Pa) $p = \rho \cdot h \cdot g$	Force (10^{-2} N) $F = p \cdot A$
1	66.5	66.5	68.5	67.2	6.58	3,62
2	59.0	59.0	61.0	59.7	5.84	3,21
3	41.5	42.0	43.5	42.3	4.15	2,28
4	-	-	-	-	-	-
5	17.0	17.0	18.5	17.5	1.71	0,94
6	9.0	9.0	6.5	8.17	0.80	0,44
7	8.5	8.5	8.5	8.50	0.83	0,46

Table 4: position 4

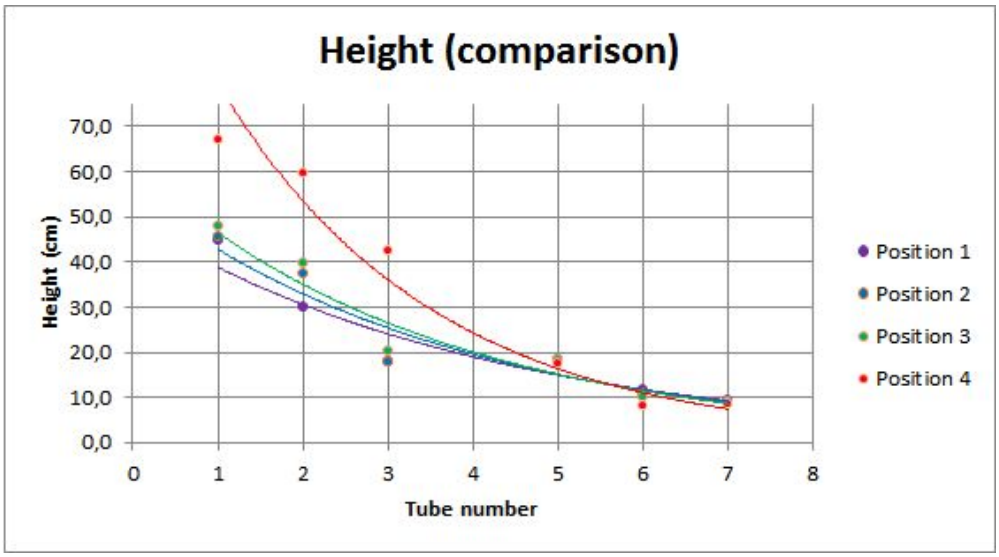


Graph 7

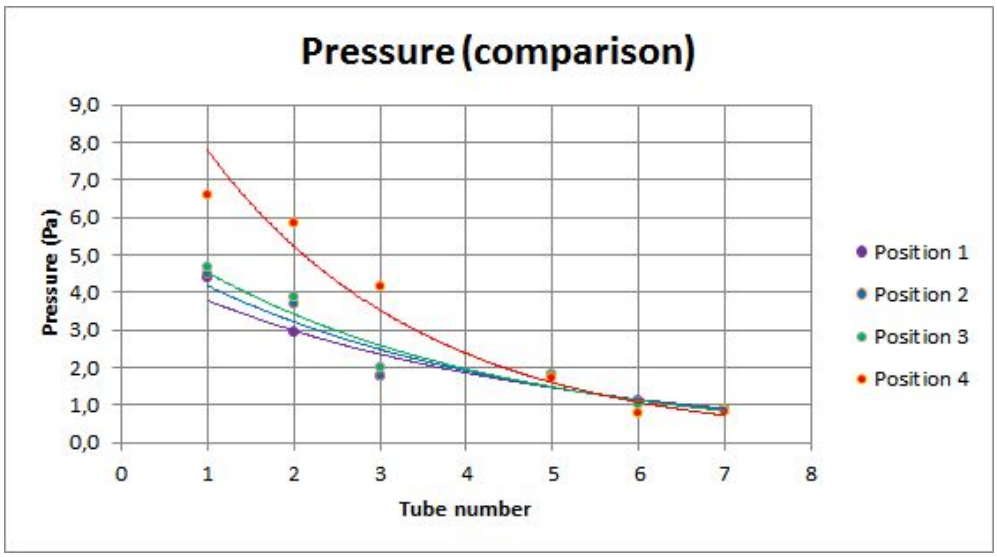


Graph 8

In table 4, the height decreases fast from 1 to 3, and decreases less fast from 5 to 7. This is visualised in graph 7. The height of number 4 can be estimated following the trend line again.
The lines in graph 7 and graph 8 are identical too.



Graph 9



Graph 10

In graph 10, graph 2, 4, 6, 8 are combined. This way, the effect of different settings of the hose clamp on the pressure in the tube can easily be compared. The step size of the different positions are equal. The graphs however, are not proportional with the step size. Especially, position 4 rises above the rest. The graphs start at different heights, but around tube number 5 they join. This shows that the pressure increases before the blockage, but does not increase after the blockage. The tighter the hose clamp, the more increase in pressure before the blockage.

6.3 Conclusion

Hagen-Poiseuille equation:

$\Delta p = \frac{8\eta \cdot L \cdot Q}{\pi r^4}$ [100]

Δp is pressure difference in Pa

η is viscosity in Pa s

L is length in m

Q is volumetric flow rate in m^3/s

r is radius in m

Bernoulli's equation in horizontal system[101]:

$E_{tot} = p + E_{kin}$

E_{tot} is total fluid energy in J

p is pressure in Pa

E_{kin} is kinetic energy in J

$E_{kin} = \frac{1}{2} m \cdot v^2$ [102]

E_{kin} is kinetic energy in J

m is mass in kg

v is velocity in m/s

$p = \rho \cdot h \cdot g$ [103]

p is pressure in Pa

ρ is density in kg/m^3

h is height in m

g is gravitational acceleration in m/s^2

From the results can be concluded that a narrowing in a tube causes a higher pressure before the narrowing only. After the narrowing, the pressure did not alter significantly.

[100] Wikipedia. (26-01-2017). *Hagen-Poiseuille equation.* Retrieved on 28-01-2017, from https://en.wikipedia.org/wiki/Hagen%E2%80%93Poiseuille_equation

[101] Keele, C.A., Neil, E. (1971). *Samson Wright's Applied Physiology.* Oxford: Oxford University Press

[102] Bouwens, R.E.A., Groot, P.A.M de, Kranendonk, W., Lune, J.P. van, Prop - van den Berg, C.M., Riswick, J.A.M.H. van, Westra, J.J. (2013). *Binas havo/vwo, table 35A.* Groningen/Houten: Noordhoff Uitgevers

[103] Bouwens, R.E.A., Groot, P.A.M de, Kranendonk, W., Lune, J.P. van, Prop - van den Berg, C.M., Riswick, J.A.M.H. van, Westra, J.J. (2013). *Binas havo/vwo, table 35C2.* Groningen/Houten: Noordhoff Uitgevers

The results of position 1, the position without hoseclamp, can be explained with the Hagen-Poiseuille equation. In position 1, the variables η, Q and r in the equation were constant for all measuring points. The length or distance from the beginning of the tube altered. From the formula can be seen that an increase in length increases the pressure difference due to friction between the fluid and the tube. This means that the further the measuring point from the start of the tube, the lower the pressure. This can be seen in graph 10, position 1.

The results of positions 2, 3 and 4 can partly be explained by Bernoulli's equation. When the hose clamp was placed on the tube, the radius and thus the area of the tube was decreased at the location of the hose clamp. Water accumulates before the clamp, resulting in a lowered velocity and thus a lower kinetic energy. The equation for kinetic energy confirms this. Because Bernoulli states that the total fluid energy remains equal, if the frictional force is neglected, the pressure must increase to compensate for the decreased kinetic energy. That is why the water levels rose before the blockade. According Pascal's formula, an increased pressure generates an increased height.

The water levels rose sharpest when comparing position 3 and 4. The difference in pressure between position 3 and 4 is significantly larger than the difference in pressure between position 2 and 3 and between position 1 and 2. The relation between the decrease in radius and pressure will be demonstrated to prove the difference.

	a **(cm)**	b **(cm)**	A_{ellipse} **(cm²)** $A_{\text{ellipse}} = \pi \cdot a \cdot b$
Position 1	0,36	0,49	0,55
Position 2	0,23	0,58	0,42
Position 3	0,13	0,63	0,26
Position 4	0,03	0,67	0,06

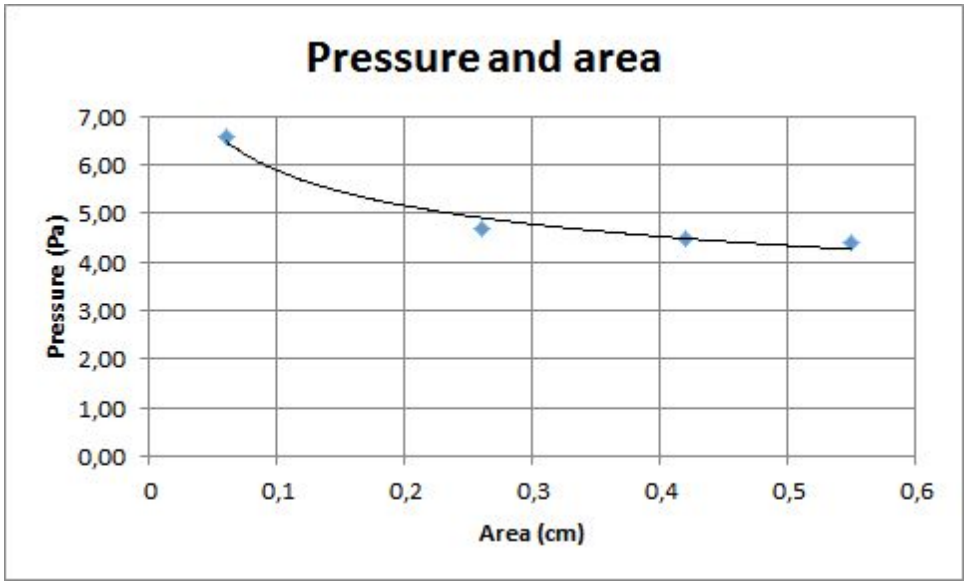
Table 5: Area of the tube where the hose clamp is placed

In table 5, the area of the ellipse at tube number 4,the place where the hose clamp is placed, is calculated.

Tube number 1	**Pressure (Pa)**	A_{ellipse} **(cm²)** $A_{\text{ellipse}} = \pi \cdot a \cdot b$	$\frac{1}{Aellipse}$ **(cm⁻²)**
Position 1	4,39	0,55	1,80
Position 2	4,47	0,42	2,39
Position 3	4,68	0,26	3,89
Position 4	6,58	0,06	15,84

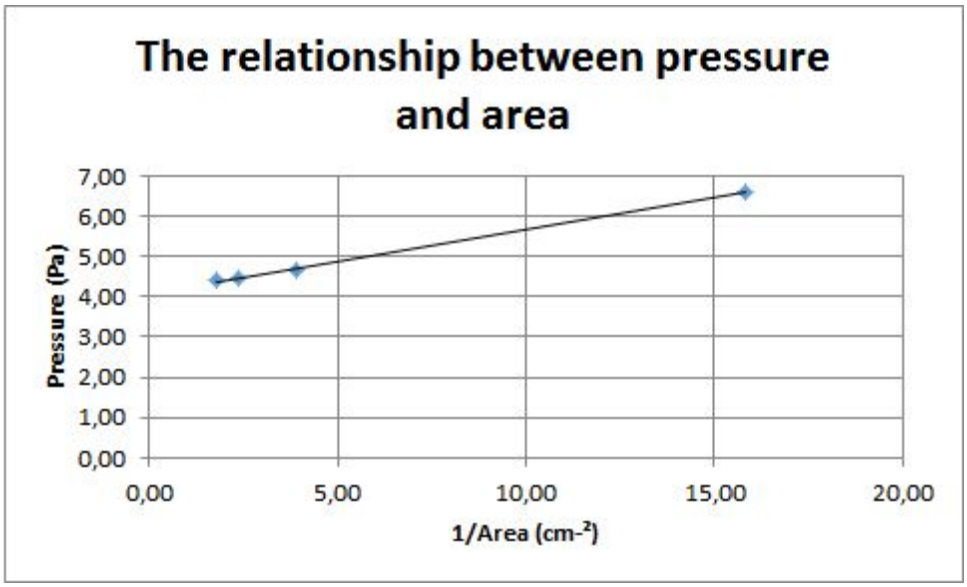
Table 6: The pressure and the area

In table 6, the pressure of tube number 1, the area of the ellipse at number 4 and one divided by the area are shown. In graph 11, pressure and area are plotted. In graph 12, pressure and one divided by are plotted.



Graph 11

In graph 11 the pressure in tube number 1 and the area of the tube where the hose clamp placed can be seen. This graph shows that the relationship between pressure and the area where the hose clamp was placed might be inversely proportional



Graph 12

Graph 12 proves that the relation between pressure in tube number 1 and area of the tube in the place where the hose clamp was placed is inversely proportional. This means that if the area is twice as small as before, the pressure is twice as big. Since the unit of area is centimetres squared and the unit of radius is cm, the relationship between pressure and radius is inversely quadratic. This can be explained by the equation mentioned below.

$\Delta p = \frac{8\eta \cdot l \cdot v}{r^2}$ [104]

Δp is difference in pressure in Pa

η is viscosity Pa s

l is length in m

v is velocity in m/s

r is radius in m

The difference in area between position 3 and 4 is bigger than the difference in area between position 2 and 3 and between 1 and 2, as can be seen in table 5. These findings explain why the difference in pressure between position 3 and 4 is bigger than the difference in pressure between position 2 and 3 and between position 1 and 2. The relationship between the area and the radius is directly quadratic proportional as can be seen by the formula for the area of an ellipse. This means that the relationship between the pressure and the radius is inversely quadratic proportional.

[104] Dalen, B. van, Dongen, J. van, Jong, R. de, Keurentjes, A., Nijhof, E.J., Vink H. Ottink, H.. (2015) *Systematische Natuurkunde Katern A VWO.* Amersfoort: ThiemeMeulenhoff

7 The effects of high blood pressure

7.1 Experiment

From the experiment can be concluded that a narrowing in a tube causes a higher pressure before the narrowing. This is a model for a human blood vessel. The narrowing in the tube acts as the plaque* in the vessel. The pressure in the blood vessel rises just like the pressure in the tube, which is high blood pressure.

7.2 High blood pressure

High blood pressure, also known as HBP or hypertension*, is a condition where the force of the blood against the artery* walls is consistently too high. Hypertension* is a silent illness; no symptoms are definitely related to HBP. Therefore, it is not self-diagnosable.[105] The only way to diagnose hypertension* is by measuring blood pressure. The set value for adults under the age of 80 is 140/90 mmHg*.[106] 140 is the systolic pressure* and 90 is the diastolic pressure*, as explained in chapter 1. If blood pressure is higher than the set value, the person is diagnosed with hypertension*.

7.2.1 Causes

HBP has many causes. In the experiment, it is shown that blood pressure increases before a blockade at a specific location in a blood vessel. Other causes include genetics*, aging, a lack of exercise and poor kidney function. In the next paragraphs, the effect of HBP as a result of a blockade is discussed.

7.3 Artery walls

Blood is transported through arteries* from the heart to every inch of the human body. Since the heart pumps the blood in a pulsing way through the arteries*, the arteries* face a fluctuating force. The pressure as a result of this force is known as blood pressure. Muscles in the artery* walls hold the vessels in shape when facing the force. High blood pressure requires the muscles to respond by pushing back harder.[107] As with exercising, the muscles that are trained will grow stronger and bigger. This makes the walls of the arteries* thicker. This results in less room for blood to flow through the artery*, which results in higher blood pressure.

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[105] American Heart Association. (31-10-2016). *What is High Blood Pressure?.* Retrieved on 02-01-2017, from http://www.heart.org/HEARTORG/Conditions/HighBloodPressure/AboutHighBloodPressure/What-is-High-Blood-Pressure_UCM_301759_Article.jsp#.WGrDHvnhDIU

[106] Nederlandse Hartstichting. (n.d.). *Hoge bloeddruk.* Retrieved on 02-01-2017, from https://www.hartstichting.nl/risicofactoren/hoge-bloeddruk

[107] Blood Pressure UK. (n.d.). *Your arteries and high blood pressure.* Retrieved on 02-01-2017, from http://www.bloodpressureuk.org/BloodPressureandyou/Yourbody/Arteries

Moreover, the more muscle in the arteries*, the stiffer the arteries*. The less elastic and flexible the arteries*, the higher the resistance. According to the formula $\Delta p = Q \cdot R$, higher resistance means a higher blood pressure.[108]

$\Delta p = Q \cdot R$ [109]
Δp is difference in pressure in Pa
Q is volumetric flow rate in m^3/s
R is resistance in Pa s/m^3

These two factors create a vicious circle that, if not intervened, can have disastrous consequences. This can be read in the following paragraphs.

7.4 Heart

The heart pumps the blood through the whole body. The more resistance in the arteries*, the higher the blood pressure, the harder the heart has to work. When a blockade develops in or near the aorta, it can result in an enlarged left half of the heart. The left ventricle* pumps the blood in the aorta, which transports it to the rest of the body. The left ventricle* is therefore the most muscular part of the heart. If it has to work harder, it will grow more muscular and will grow bigger, just as the artery* walls. This causes the left ventricle* to thicken and stiffen, a condition known as left ventricular hypertrophy*. The risk of heart attack, heart failure* and sudden cardiac death* increases significantly. Also, heart failure* due to worn out muscles can occur, since the heart is overworking all the time. [110]

7.5 Aortic rupture

Aortic rupture* is the breach of the largest and most important artery* in the human body, the aorta.[111] It is a fatal condition due to the amount of blood that leaves the aorta when ruptured. As a result of high pressure, the blood leaves the aorta with speed. Since all the blood pumped away by the left ventricle* passes through the aorta before it splits up, most of the blood will leave the aorta through the rupture. This may cause a shock or death.[112] The symptoms are unconsciousness and pain in the lower half of the torso. Also the skin may appear blue, a fast heart rate can be identified and blood pressure can be low.

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[108] Hartwijzer. (n.d.). *Hoge bloeddruk.* Retrieved on 02-01-2017, from http://www.hartwijzer.nl/Hoge_bloeddruk.php
[109] Dalen, B. van, Dongen, J. van, Jong, R. de, Keurentjes, A., Nijhof, E.J., Vink H. Ottink, H.. (2015) *Systematische Natuurkunde Katern A VWO.* Amersfoort: ThiemeMeulenhoff
[110] Mayo Clinic Staff (n.d.). *High blood pressure (hypertension).* Retrieved on 08-01-2017, from http://www.mayoclinic.org/diseases-conditions/high-blood-pressure/in-depth/high-blood-pressure/art-20045868
[111] Wikipedia. (26-11-2016). *Aortic rupture.* Retrieved on 08-01-2017, from https://en.wikipedia.org/wiki/Aortic_rupture
[112] Wikipedia (15-09-2016). *Traumatic aortic rupture.* Retrieved on 08-01-2017, from https://en.wikipedia.org/wiki/Traumatic_aortic_rupture

Aortic rupture* can be caused by accidents at high speeds, such as car accidents or fall from great heights. However, usually it happens when the artery* is already damaged, as a result of atherosclerosis*. [113] Aortic rupture* is therefore indirectly caused by hypertension.

7.6 Coronary artery disease

A blockade consisting of plaque* located in the coronary arteries* is known as coronary artery disease*.[114] These arteries* supply the heart with oxygenated blood. In case of blockage, parts of the heart are cut off of oxygen which results in malfunctioning of the heart. Symptoms are chest pain, heart attack and irregular heart rhythms.[115] When a blood clot* gets stuck at the obstruction, suddenly cutting off all blood supply, permanent heart damage will be the result.[116]

7.7 Brain

The brain depends greatly on blood supply. The cerebral circulation*, the blood that is transported to the brain, is typically 750 ml/min which is about 15% of blood in the body.[117] A high blood pressure in the brain can lead to several problems. The first is a transient ischemic attack*, abbreviated as TIA, also known as a mini stroke. It is an interruption in blood supply to the brain. It is a warning for a regular stroke. This is a condition when a part of the brain is supplied with too little oxygen and nutrients, which results in brain cells dying. It can also cause blood vessels to narrow or rupture. A rupture in the brain is called brain hemorrhage*. The blood flowing from the rupture will cause brain cells to die.[118]

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[113] Wikipedia. (15-05-2015). *Aortaruptuur.* Retrieved on 08-01-2017, from https://nl.wikipedia.org/wiki/Aortaruptuur

[114] MedlinePlus (n.d.). *Coronary Artery Disease.* Retrieved on 08-01-2017, from https://medlineplus.gov/coronaryarterydisease.html

[115] Mayo Clinic Staff (w.d). *High blood pressure (hypertension).* Retrieved on 08-01-2017, from http://www.mayoclinic.org/diseases-conditions/high-blood-pressure/in-depth/high-blood-pressure/art-20045868

[116] MedlinePlus (n.d.). *Coronary Artery Disease.* Retrieved on 08-01-2017, from https://medlineplus.gov/coronaryarterydisease.html

[117] Wikipedia (07-01-2017). *Cerebral circulation.* Retrieved on 08-01-2017, from https://en.wikipedia.org/wiki/Cerebral_circulation

[118] WebMD (n.d.) *Brain Hemorrhage.* Retrieved on 29-01-2017, from http://www.webmd.com/brain/brain-hemorrhage-bleeding-causes-symptoms-treatments#1

8 Prevention and cure

8.1 Prevention

Cholesterol* is measured in the quantity of triglycerides, HDL* and LDL*. The diagnosis of a high cholesterol* actually means that the HDL/LDL* ratio is too low and that the quantity of triglycerides is too high. To lower the risk of atherosclerosis* this ratio must be increased and the quantity of triglycerides must be lowered. This will cause plaque* forming to be stalled. However, this does not erase all of the plaque* that has already build up in the arteries.

As discussed in chapter 4.4 there are numerous factors that influence cholesterol* levels. By changing not only the amount of fat, but also the kind of fat consumed, the HDL/LDL* ratio can be increased. From the study described in paragraph 4.4.1, it can be deduced that eating unsaturated fats* with a cis-bond* is the best option when eating fatty foods. While it is advised to reduce fat intake, this does not mean that fat should be eliminated from the diet entirely. The advised daily intake of fat is 70 grams, of which 20 grams or less is advised for saturated fats*.[119]

A 2012 study[120] showed that there is a strong correlation* between BMI*, body fat percentage and the fat distribution pattern of blood lipids. The higher the BMI* and body fat percentage, the more blood lipids present, particularly triglycerides* and cholesterol*. This can be explained by the fact that blood fats need a transporter such as LDL* and HDL*. The amount of blood lipids is proportional to the amount of fatty food consumed and if more fatty food is consumed, the BMI* will be higher. Lowering the BMI* does not directly impact cholesterol* levels, but the means to lower the BMI* also improve cholesterol* levels.[121] This means a high body mass index* does not necessarily indicate high cholesterol* levels. However, there is a strong correlation*.

As mentioned in paragraph 4.4.3, smoking has been found to influence the levels of HDL*. The more cigarettes smoked, the less HDL* that can be found in the blood. The difference in HDL* between smokers and nonsmokers has been found to be 4 mg/dL in men and 6 mg/dL in women.[122] This means that people who smoke have a higher chance of experiencing atherosclerosis*.

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[119] Voedingscentrum. (n.d.). *Referentie-inname.* Retrieved on 24-01-2017, from http://www.voedingscentrum.nl/encyclopedie/referentie-inname.aspx

[120] Zamani, A., Beni, M. Akbarpour, Abadi, M. Assar Zadeh Noosh. (2012). *Relationship between body compostion with Blood Lipids profile.* Retrieved on 12-12-2016, from http://www.imedpub.com/articles/relationship-between-body-composition-with-blood-lipids-profile.pdf

[121] Helderman D., Phifer C.. (02-2009). *Nutrition questions? Ask the Dietitian.* Retrieved on 12-12-2016, from https://healthandwellness.vanderbilt.edu/news/files/hpBodyFatAndCholesterol.pdf

[122] Garrison, R.J., Kannel, W.B., Feinleib, M., Castelli, W.P., McNamara, P.M., Padgett, S.J. (1979) *Cigarette smoking and HDL cholesterol the Framingham offspring study* Retrieved on 24-01-2017, from http://www.sciencedirect.com/science/article/pii/0021915078901491

Furthermore, exercise has also been found to influence cholesterol* levels, as mentioned in paragraph 4.4.3. The first change after starting an exercise routine is the lowering of triglyceride* levels. When someone keeps up an exercise routine, their HDL* levels will rise. It is not yet understood how exercise causes these changes.[123] Both the decrease of the triglycerides* and the increase of HDL* result in a lower risk of forming of plaque*.

8.2 Medication

Atherosclerosis* does not usually show symptoms before it reaches a state in which its symptoms can not be prevented. This can be explained using the conclusion from the experiment in chapter 6. When the radius decreases, the pressure rises quadratically. The pressure only becomes noticeably high when the buildup of plaque* is so high that preventing further buildup is not enough to lower the risk of the effects of atherosclerosis* discussed in chapter 7. When atherosclerosis* has reached this stage, medication is often prescribed.

8.2.1 Diuretics

Diuretics are usually the first choice for treating hypertension*.[124] This type of medication promotes the excretion of water. [125] This lowers the blood volume. A common side effect of diuretics therefore is frequent urination.[126]

$Q = \frac{V}{t}$ [127]

Q is volumetric flow rate in m^3/s

V is volume in m^3

t is time in s

$\Delta p = Q \cdot R$ [128]

Δp is difference in pressure in Pa

Q is volumetric flow rate in m^3/s

R is resistance in Pa s/m^3

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[123] Haskell, W. L. (1984) *The Influence of Exercise on the Concentrations of Triglyceride and Cholesterol in Human Plasma.* Retrieved on 25-01-2017, from http://journals.lww.com/acsm-essr/Citation/1984/01000/The_Influence_of_Exercise_on_the_Concentrations_of.9.aspx

[124] Mayo Clinic Staff. (n.d.). *High blood pressure (hypertension).* Retrieved on 21-01-2017, from http://www.mayoclinic.org/diseases-conditions/high-blood-pressure/basics/treatment/con-20019580

[125] Wikipedia. (06-01-2017). *Diuretic.* Retrieved on 21-01-2017, from https://en.wikipedia.org/wiki/Diuretic

[126] WebMD. (n.d.) *HIgh Blood Pressure and Diuretics (Water Pills).* Retrieved on 21-01-2017, from http://www.webmd.com/hypertension-high-blood-pressure/guide/diuretic-treatment#1

[127] Dalen, B. van, Dongen, J. van, Jong, R. de, Keurentjes, A., Nijhof, E.J., Vink H. Ottink, H.. (2015) *Systematische Natuurkunde Katern A VWO.* Amersfoort: ThiemeMeulenhoff

[128] Dalen, B. van, Dongen, J. van, Jong, R. de, Keurentjes, A., Nijhof, E.J., Vink H. Ottink, H.. (2015) *Systematische Natuurkunde Katern A VWO.* Amersfoort: ThiemeMeulenhoff

Since $Q = \frac{V}{t}$ and $\Delta p = Q \cdot R$, the pressure decreases when the volume decreases. Therefore, diuretics work as a pressure-lowering medicine.

8.2.2 Beta blockers

Beta blockers are another type of medicine used to decrease blood pressure. They block the effect of adrenaline and noradrenaline.[129] These hormones* mediate the fight-or-flight response*. One of the body's reaction to the fight-or-flight response* is the acceleration of heart action.[130] By blocking the receptors of the hormones*, the effect of stress hormones* is weakened. Therefore, beta blockers lower the heart rate and the force of the heartbeat.[131] When the heartbeat decreases, the time period in between each heartbeat increases. The formula $Q = \frac{\Delta V}{\Delta t}$ shows that the volumetric flow rate decreases when time increases. $\Delta p = Q \cdot R$, therefore if the volumetric flow rate decreases, the pressure decreases.

$p = \frac{F}{A}$ [132]
F is force in N
p is pressure in Pa
A is area in m^2

When the force decreases, the pressure decreases. Thus, when beta blockers decrease the forces in the arteries*, blood pressure decreases as well. Beta blockers also block the production of angiotensin II.[133] It causes vasoconstriction*, the narrowing of the blood vessels as a result of the contraction of the muscular wall.[134] According to the formula $R = \frac{8\eta \cdot l}{\pi r^4}$,this increases blood pressure.[135]

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[129] Blood Pressure UK (05-2009). *Beta-blockers - blood pressure medication.* Retrieved on 21-01-2017, from http://www.bloodpressureuk.org/BloodPressureandyou/Medicines/Medicinetypes/Othermeds/Beta-blockers

[130] Wikipedia. (19-01-2017). *Fight-or flight response.* Retrieved on 21-01-2017, from https://en.wikipedia.org/wiki/Fight-or-flight_response#Function_of_physiological_changes

[131] WebMD. (n.d.). *Beta-Blockers for High Blood Pressure.* Retrieved on 21-01-2017, from http://www.webmd.com/hypertension-high-blood-pressure/beta-blockers-for-high-blood-pressure

[132] Bouwens, R.E.A., Groot, P.A.M de, Kranendonk, W., Lune, J.P. van, Prop - van den Berg, C.M., Riswick, J.A.M.H. van, Westra, J.J. (2013). *Binas havo/vwo, table 35C1.* Groningen/Houten: Noordhoff Uitgevers

[133] Blood Pressure UK (05-2009). *Beta-blockers - blood pressure medication.* Retrieved on 21-01-2017, from http://www.bloodpressureuk.org/BloodPressureandyou/Medicines/Medicinetypes/Othermeds/Beta-blockers

[134] Wikipedia. (11-10-2016). *Vasoconstriction.* Retrieved on 21-01-2017, from https://en.wikipedia.org/wiki/Vasoconstriction

[135] Wikipedia. (13-01-2017). *Angiotensin.* Retrieved on 23-01-2017, from https://en.wikipedia.org/wiki/Angiotensin

$R = \frac{8\eta \cdot l}{\pi r^4}$ [136]

R is resistance in Pa s/m^3

η is viscosity in Pa s

l is the length of the blood vessel in m

r is the radius of the blood vessel in m

A decrease in the amount of angiotensin II therefore promotes relaxation of the muscles in the wall of the blood vessel. This results in a decrease in blood pressure. This effect can also be created by using angiotensin II receptor blockers, also known as ARBs. In contrast to beta blockers, ARBs prevent angiotensin II from binding to receptors by blocking them, whereas beta blockers prevent the production.

8.2.3 Calcium channel blockers

Calcium channel blockers are another type of medication used to cure hypertension.[137] They disrupt the movement of calcium through calcium channels. The calcium concentration has different effects on different types of cells. Calcium channel blockers reduce contraction in the muscular walls of the arteries*, which results in vasodilation*.[138] Vasodilation* is the widening of blood vessels. [139]

$R = \frac{8\eta \cdot l}{\pi r^4}$ [140]

R is resistance in Pa s/m^3

η is viscosity in Pa s

l is the length of the blood vessel in m

r is the radius of the blood vessel in m

When a blood vessel widens, the radius increases. Therefore, the resistance decreases. The relationship between pressure and resistance is $\Delta p = Q \cdot R$. When the resistance decreases, pressure decreases. Calcium channel blocker also affect the heart muscles, reducing the force at which the heart contracts.[141] Since $F = p \cdot A$ applies, the pressure decreases even more. They also lower heartbeat by slowing down the conduction of electrical activity. As proven in 8.2.2, a slower heartbeat decreases pressure.

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[136] Dalen, B. van, Dongen, J. van, Jong, R. de, Keurentjes, A., Nijhof, E.J., Vink H. Ottink, H.. (2015) *Systematische Natuurkunde Katern A VWO.* Amersfoort: ThiemeMeulenhoff

[137] Mayo Clinic Staff. (n.d.). *High blood pressure (hypertension).* Retrieved on 24-01-2017, from http://www.mayoclinic.org/diseases-conditions/high-blood-pressure/basics/treatment/con-20019580

[138] Wikipedia. (24-12-2016). *Calcium channel blocker.* Retrieved on 24-01-2017, from https://en.wikipedia.org/wiki/Calcium_channel_blocker#Mechanism_of_action

[139] Wikipedia. (10-01-2017). *Vasodilation.* Retrieved on 24-01-2017, from https://en.wikipedia.org/wiki/Vasodilation

[140] Dalen, B. van, Dongen, J. van, Jong, R. de, Keurentjes, A., Nijhof, E.J., Vink H. Ottink, H.. (2015) *Systematische Natuurkunde Katern A VWO.* Amersfoort: ThiemeMeulenhoff

[141] Wikipedia. (24-12-2016). *Calcium channel blocker.* Retrieved on 24-01-2017, from https://en.wikipedia.org/wiki/Calcium_channel_blocker#Mechanism_of_action

8.3 Physical treatments

Physical treatments can be used to lower the blood pressure in a specific artery*. Unlike medication, they do not affect the whole body. They are usually used to cure coronary artery disease* and to prevent aortic rupture*, since the rupture of those arteries* cause most damage. This can be read in paragraphs 7.6 and 7.7.

8.3.1 Bypass

The technical term for bypass is Coronary Artery Bypass Grafting*, or CABG. Other blood vessels, preferably an artery* from the chest or a vein* from the leg, are used to create an alternative route for the blood to reach the coronary artery*. The detour is used to avoid the narrowing without removing the deposed plaque*. In figure 12 B can be seen how the bypass would be applied. A disadvantage of this operation is that the heart must be accessible, and therefore the sternum* must be broken. This also creates a big wound on the chest. Another disadvantage is that the heart must be shut down, at least partly. To accomplish this, a lot of technology is required.[142]

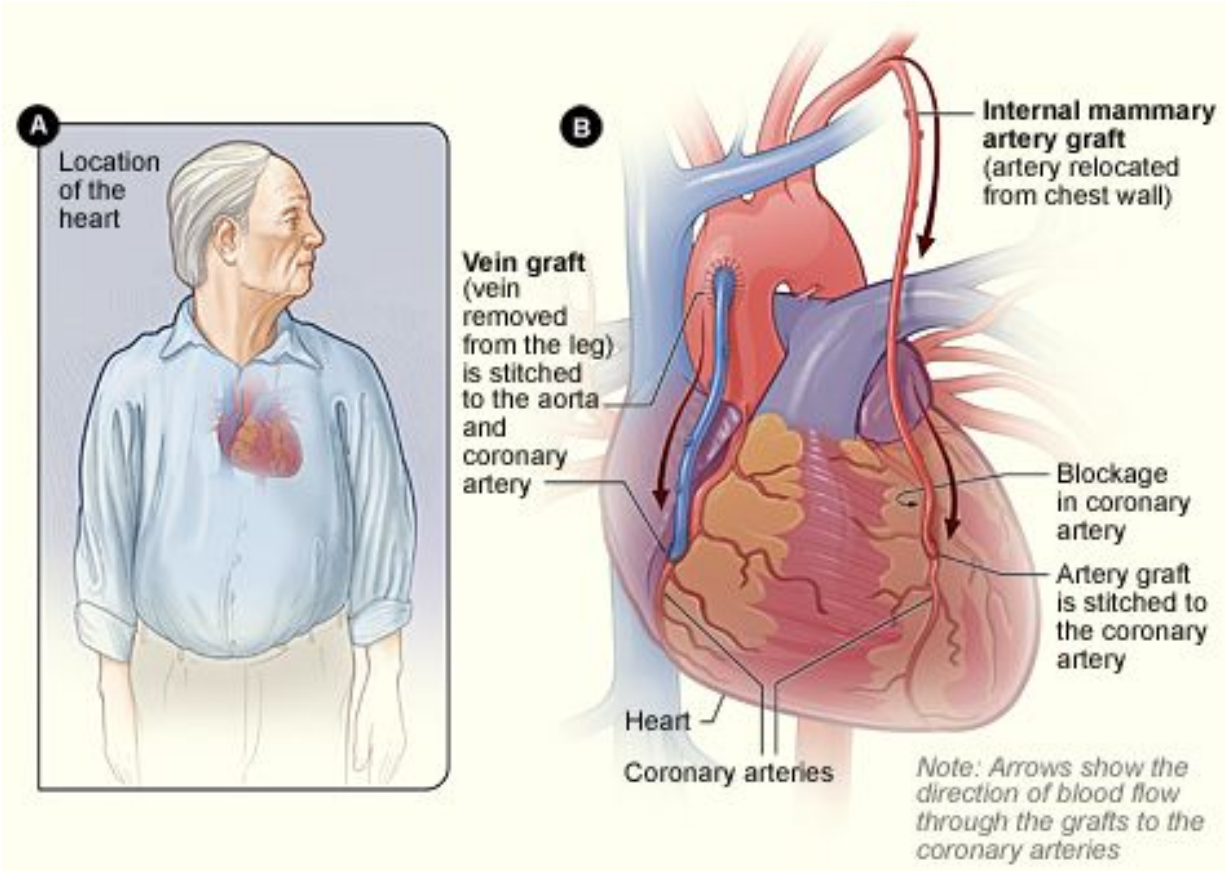

Figure 12: application of bypass[143]

[142] Hartstichting. (n.d.). *Bypass- of omleidingsoperatie.* Retrieved on 24-01-2017, from https://www.hartstichting.nl/behandelingen/bypass-of-omleidingsoperatie

[143] National Heart, Lung and Blood Institute (n.d.) *What Is Coronary Artery Bypass Grafting?.* Retrieved on 24-01-2017, from https://www.nhlbi.nih.gov/health/health-topics/topics/cabg

8.3.2 Percutaneous Coronary Intervention

The less invasive and therefore more preferable option is Percutaneous Coronary Intervention*, also known as PCI. The aim of PCI is to open up coronary arteries* that are blocked or narrowed by plaque*. A catheter* is inserted in the wrist and can be guided by x-rays. A contrast dye* is used to highlight the blockade. When the catheter* is at the location of the blockade of plaque*, a balloon is inflated to relieve the narrowing[144]. In addition, a stent* can be placed.[145] A stent* is a small mesh tube.[146] It is placed at the location of the narrowing to prevent narrowing in the future. The stent* prevents the deposition of materials which cause a blockage.

[144] Wikipedia. (23-01-2017). *Percutaneous coronary intervention.* Retrieved on 24-01-2017, from https://en.wikipedia.org/wiki/Percutaneous_coronary_intervention

[145] National Heart, Lung, and Blood Institute. (n.d.). *Percutaneous Coronary Intervention.* Retrieved on 24-01-2017, from https://www.nhlbi.nih.gov/health/health-topics/topics/angioplasty

[146] National Heart, Lung, and Blood Institute. (n.d.). *What Is a Stent?.* Retrieved on 24-01-2017, from https://www.nhlbi.nih.gov/health/health-topics/topics/stents

Conclusion

Subquestions

To answer the research question, the subquestions are answered first.

1. **What is the human blood circulation?**
   Human blood consists of blood plasma and solid constituents. It is the main way of transport for oxygen and nutrients, amongst others, through the body. Blood is pumped through the body by the heart in a double circulatory system once a minute. Oxygen-enriched blood from the lungs leaves the left ventricle through the aorta, the main artery of the human body. It has a very thick, elastic, muscular wall to absorb the high pressure the heart exerts. The blood pressure is highest in the aorta and is pulsating. The blood pressure decreases each time the aorta branches out in the arterioles, capillaries, venules and veins, respectively. Veins carry blood poor of oxygen to the heart and have thinner walls than arteries due to the lack of the pulsating force of the heart.

2. **What types of fat enter the human body?**
   The human body needs fat to function. Molecules of fat consist of three fatty acid molecules connected to a glycerol molecule and are called triglycerides. Molecules of a saturated fat consist of fatty acids in which all carbon atoms have the maximum number of hydrogen atoms attached. They are considered unhealthy; a high intake of saturated fats is proven to increase levels of LDL-cholesterol. Unsaturated fats have room available for hydrogen atoms. They can be mono- or polyunsaturated and trans or cis configurated. Cis unsaturated fats are considered healthy. Trans fats made in the process of partial hydrogenation are found to be very unhealthy.

3. **How is fat processed by the human body?**
   Food is processed to energy in the digestive system. The digestion of fats starts in the duodenum. Bile salts from the gall bladder emulsify the fat to enable the enzyme lipase to operate. In cooperation with colipase, lipase splices the triglycerides into fatty acids, mono- and diglycerides. Together with other fat soluble nutrients they form micelles and directly enter the lymphatic system, which merges later on with the blood circulation. Chylomicrons transport the nutrients to the cells for building membranes. The residue of the chylomicrons is removed by the liver. Free fatty acids are resynthesized and stored in white adipose tissue.

4. **What are the causes of a high LDL-cholesterol percentage in the blood?**
   LDL- and HDL-cholesterol are lipoproteins that carry the fatty cholesterol through the blood. A diet predominantly consisting of fat in the form of unsaturated fat results in a HDL/LDL ratio greater than 1. When the consumed fats consist mainly of trans unsaturated fats HDL/LDL ratio will be lower. A diet consisting of mostly saturated fats will cause both HDL and LDL levels to be higher than average, which does not significantly alter the ratio. On average, people with a higher BMI have a higher level of LDL and HDL. Smoking is related to higher levels of HDL. The older the person, the more likely cholesterol levels are high. Genetics also determine someone's LDL and HDL levels.

5. **How are the blood vessels being clogged?**
   LDL deposits a part of the cholesterol it is carrying on the inside wall of a blood vessel. HDL picks this excess cholesterol up and transports it to the liver. When this does not happen macrophages will try to transport the cholesterol out of the blood. The macrophage is unsuccessful and becomes a foam cell. This foam cell sticks to the wall of the blood vessel. Other excesses of cholesterol will get stuck behind this foam cell, causing another macrophage to become a foam cell there. This cycle continues and the buildup will slowly turn into plaque. This buildup of plaque is called atherosclerosis.

6. **What is the influence of a clogged blood vessel on the blood pressure surrounding that clog?**
   To research the influence of a blockage on the blood pressure, an experiment is conducted. The experiment is a model consisting of tubes to represent a human blood vessel. From the experiment can be concluded that a narrowing in a tube causes a higher pressure before the narrowing only. The narrowing in the tube acts as the plaque in the vessel. The pressure in the blood vessel rises just like the pressure in the tube, which is high blood pressure.

7. **What are the effects of high blood pressure on the human body?**
   The condition high blood pressure or hypertension is characterised by a blood pressure higher than 140/90 mmHg. This set value is for adults younger than 80 years. One cause of hypertension is a blockade in a blood vessel. The effect of hypertension on the arteries is that they grow stronger and bigger, making the walls of the blood vessel thicker and less elastic. As a result, the inner diametre decreases. This results in a higher blood pressure. If this happens in the aorta, it can lead to an enlarged left half of the heart, which increases health risks. Also, the aorta can rupture due to high pressure. A blockade in a coronary artery is known as coronary artery disease. It results in malfunctioning of the heart, since the heart is partly deprived of oxygen. High blood pressure in the brain can cause a TIA. It happens when the brain is supplied with too little oxygen and nutrients, resulting in dying brain cells. Also blood vessels can narrow or rupture.

8. **How can high blood pressure be prevented?**

A high blood pressure due to plaque can be prevented by improving the HDL/LDL cholesterol ratio. Eating less fat and substituting other kinds of fat with unsaturated fats will improve the ratio. Quitting smoking will increase HDL levels and lowering the risk of plaque formation. Losing weight can contribute to improve the cholesterol ratio, as does exercising.Improving lifestyle can also help to cure hypertension. Also medication can cure HBP. Diuretics, beta blockers and calcium channel blockers are types of medication that can cure hypertension. Physical treatments are a Coronary Artery Bypass Grafting, where another blood vessel is used to create a detour for the blood. Another, less invasive physical treatment is Percutaneous Coronary Intervention. A catheter with a balloon at the end is inserted. The balloon is inflated at the location of the obstruction. A stent can be placed to prevent narrowing in the future.

Research question

The research question of this paper is: how is blood pressure affected by fat? The answer to this question is: blood pressure increases as a result of cholesterol* deposits in the blood vessels.

Expectation

The expectation is: if fat causes a blockage in the vessel, then the pressure in the model will increase if a narrowing occurs in the model. The expectation is met, since the results show that the pressure indeed increases when the hose clamp is placed. The results also prove that the pressure quadratically increases when the radius of the narrowing decreases linearly.

Hypothesis

The hypothesis of this research paper is: fat can cause a blockage in the blood vessel, resulting in a higher blood pressure. The hypothesis is not rejected. Based on the literary research, it is proven that a blockade is caused by the depositing of types of fat in the blood vessels. The experiment shows that the blood pressure rises when a narrowing occurs.

Discussion

For future repetition of the experiment, a few points of improvements are listed below. When implemented, these changes to the experiment could make the results more accurate and representative

First of all, a blood-like fluid or even real blood could be used. This eliminates the differences between the tested liquid, water, and the modelled liquid, blood. For example, water is less viscous than blood. Blood also contains solid constituents and therefore is a suspension. Water, on the other hand, is a clear liquid containing no undissolved substances. These differences would be taken care of using real blood or a blood-like liquid. The results would be altered, since viscosity plays a role in the pressure difference over distance, according to the Hagen-Poiseuille equation. The results acquired would be more similar to the behaviour of blood.

Moreover, the used model was built using materials available at home, since professional equipment was not available. For example, the walls of blood vessels are able to expand a little and can contracted due to the muscles in the walls. The tube used as a representation of a blood vessel was not able to contract or expand. To represent the blood vessel more accurately, a tube with a less stiff wall could be used to represent the expanding of the vessel during the contracting of the heart.

Furthermore, the pump used in this experiment was not representative of the movement of the heart. The used pump created a steady flow, while the heart pumps with pulses. To overcome this difference, a pulsating pump can be used to simulate a heartbeat through the model accurately.

In addition, the small measuring tubes were connected to the big tube by drilling a hole in the big tube, and preventing leakage by wrapping rope around the connection. A problem with this set-up is that the measuring tubes are able to sink in the big tube a little, disturbing the flow and creating a systematic mistake. To prevent the such measuring mistakes, a professional pressure gauge could be integrated in the model. This would eliminate not only the systematic mistake of the primitive connection between the tubes, but also error of the hand-drawn measuring lines on the model. Moreover, the error of measurement that occurred when the measurements were rounded off to the nearest half centimetre would be prevented.

An obstruction was simulated by a hose clamp. However, this hose clamp squeezed the tube together from the outside, while a real blockage of plaque narrows the vessel from the inside. Placing a blockade inside the vessel using a material that resembles plaque would further increase the accuracy of the experiment.

Another way of improving the experiment involves the conditions in which the experiment was executed. The experiment was conducted with the model outside in the cold. A real blood vessel lies in the body, where the temperature is 37°C, which is much hotter than the temperature the experiment was done in. The viscosity of a liquid decreases when its temperature is increased.[147] Since viscosity plays a role in the pressure difference over distance, as the Hagen-Poiseuille equation shows, executing the experiment in conditions similar to the conditions in the human body would render the results more representative.

Further research on this subject could be focused on how exercise increases HDL-levels in the blood. This paper shows that saturated and trans fats influence the HDL/LDL-ratio negatively. Further research could be on what other factors, like exercising, do to that ratio. Understanding these mechanisms would benefit those who suffer of cardiovascular disease and might provide them with a cure to their disease.

[147] Wikipedia. (30-01-2017). *Temperature dependence of liquid viscosity.* Retrieved on 01-02-2017, from https://en.wikipedia.org/wiki/Temperature_dependence_of_liquid_viscosity

Evaluation

S.A. Nijhuis

Writing this paper was a rollercoaster ride, with ups and downs. The subject meets my interests of food, the exact subject and making the world a better place. Whereas the research we have done might not be of world-changing size, cardiovascular disease does affect many people across the globe. The knowledge I acquired might be of importance in the future, when I might be capable of doing world-changing research.This motivated me to continue writing and learn as much a I could whilst writing. Also the others were of great motivation. As a team, Leon, Eva and I helped each other out when needed. Communication between us was very efficient, and also the communication with the supervisor mr. Dettmers was strong. The fact that we were able to criticize the work of others was also very helpful in raising the paper to a higher level. The downside however, was the size and time limit of the project. Especially the last month has caused a lot of stress. It was then, I realized we might have been a bit enthusiastic, and should have narrowed down the subject even more. Nonetheless, I think we delivered a great research paper.

L.S. Besseling

Working on this research paper required a lot of time and effort; time and effort happily spent. Although it was difficult sometimes, as a team we pulled together and worked our way through it. Working together many evenings certainly improved my skills of working in a group. Luckily my peers were two of my best friends, but they were not hesitant to point out any mistakes. This critical feedback was useful and improved the quality of our research paper. It was very interesting conducting an experiment using a model built from scratch. Trying to find solutions for simple problems like a leak was fun to do and sparked our creativity. When we could not figure it out ourselves, we received help from our supervisor, mr. Dettmers, who paved a rough path for the set-up of experiment. While we had a good time schedule, much work was still left to do in the final weeks. We worked late in the evenings, but in the end I think that we reached a great final result.

E.C.M. Plas

Working on this research paper was a very interesting experience. I have learned a lot about myself and my friends in the process of making this paper. I prefered working on the model and calculating with the measurements over working on the theoretical research. This gave me more insight in which subjects I do or do not like. I realized I have a very short attention span when working together with my friends. Working on this paper has taught me how to be more productive, even in more social situations. The communication with our supervisor mr. Dettmers was strong. I felt like communication was not a problem at all within this group. This paper has tested our friendship and I believe we have passed with flying colours. I believe we can be very proud of ourselves for the work we delivered.

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Special thanks to R.J. Dettmers for supervising the process of writing this research and inspiration for the experiment.
Special thanks to T.A.M. Nijhuis for providing materials and ideas for the model, catering and providing a work space.
Special thanks to L.P.E. Besseling-Wagenaar for catering and providing a work space.
Special thanks to A.G. Besseling for catering and providing a work space.
Special thanks to E.J. Plas for inspiration, catering and providing a work space.
Special thanks to M.J.J Plas-Dudink for catering and providing a work space.
Special thanks to E.T. Bol for advising us how to prove the relationship between pressure and radius.

Logbook:

Date and time	Description	Name	Time spent
02-02-2017 | 22:15	Converting document to pdf-file, lay-out, solving comments, title	Eva	1 hour
02-02-2017 | 21:45	Converting document to pdf-file, lay-out, solving comments, title	Eva	30 min
02-02-2017 | 21:30	Converting document to pdf-file, lay-out, solving comments, title	Leon	1 hour and 30 min
02-02-2017 | 20:45	Wordlist, solving comments, APA, layout, title	Sofie	2 hours and 30 min
02-02-2017 | 16:00	Word list	Sofie	1 hour
02-02-2017 | 14:15	Checking conclusion, thinking of title and word list	Sofie	1 hour
02-02-2017 | 14:00	Improving experiment, word list and index	Eva	1 hour
02-02-2017 | 00:01	Summary, discussion, conclusion experiment, sources, word list, introduction, checking, acknowledgements, evaluation, solving comments, layout	Sofie	1 hour and 1 min
02-02-2017 | 00:01	Summary, discussion, conclusion experiment, sources, word list, introduction, checking, acknowledgements, evaluation, solving comments, layout	Leon	1 hour and 1 min
02-02-2017 | 00:00	Summary, discussion, conclusion experiment, sources, word list, introduction, checking, acknowledgements, evaluation, solving comments, layout	Eva	1 hour
01-02-2017 | 16:30	Summary, discussion, conclusion experiment, sources, word list, introduction, checking, acknowledgements, evaluation, solving comments, layout	Sofie	7 hours and 29 min

01-02-2017 | 15:00	Summary, discussion, conclusion experiment, sources, word list, introduction, checking, acknowledgements, evaluation, solving comments, layout	Leon	8 hours and 59 min
01-02-2017 | 14:30	Summary, discussion, conclusion experiment, sources, word list, introduction, checking, acknowledgements, evaluation, solving comments, layout	Eva	9 hours and 29 min
01-02-2017 | 10:10	Meeting mr. Bol conclusion experiment	Sofie	20 min
01-02-2017 | 10:10	Meeting mr. Bol conclusion experiment	Leon	20 min
31-01-2017 | 21:30	Sources, introduction (observation), improving research question, evaluation	Sofie	1 hour and 30 min
31-01-2017 | 21:00	Improving chapter 5 and 8 Working on the wordlist	Eva	1 hour and 30 min
31-01-2017 | 19:00	Word list chapter 2, lay out	Leon	45 min
31-01-2017 | 15:00	Improving chapters 4,5, and 8	Eva	2 hour
30-01-2017 | 21:30	Sources + APA	Sofie	2 hour
30-01-2017 | 20:30	Improving chapter 4	Eva	1 hour and 30 min
30-01-2017 | 19:00	Improving chapter 1 and 2, word list chapter 1 and 2	Leon	2 hours
30-01-2017 | 17:15	Sources	Sofie	1 hour
29-01-2017 | 13:30	Checking of grammar, spelling, content. Conclusion experiment, word list, improve chapter 3, 6, 7, 8, conclusion.	Sofie	9 hours and 30 min
29-01-2017 | 13:30	Checking of grammar, spelling, content. Conclusion experiment, word list, improve conclusion.	Leon	8 hours

29-01-2017 | 13:30	Checking of grammar, spelling, content. Conclusion experiment, word list.	Eva	8 hours
28-01-2017 | 12:30	Experiment: conclusion (fluid dynamics research)	Leon	3 hours
25-01-2017 | 14:00	Conclusion, checking, introduction, planning, questions for Dettmers	Leon	8 hours
25-01-2017 | 14:00	Introduction, conclusion, checking, chapter 8, planning, question for mr Dettmers	Sofie	8 hours
25-01-2017 | 14:00	Chapter 8, Conclusion, Checking, Planning, Questions for Dettmers	Eva	8 hours
25-01-2017 | 10:30	Meeting about presentation	Sofie	1 hour
25-01-2017 | 10:30	Meeting about presentation; division of subjects	Leon	1 hour
25-01-2017 | 10:30	Meeting about presentation	Eva	1 hour
24-01-2017 | 20:30	Chapter 8	Sofie	1 hour and 30 min
24-01-2017 | 16:30	Introduction: solving comments	Leon	30 min
24-01-2017 | 15:00	Literary research chapter 8	Eva	2 hours
23-01-2017 | 16:00	Chapter 8 + resolving comments	Sofie	1 hour and 45 min
23-01-2017 | 15:30	Method: solving comments Chapter 5: adding/solving comments + necessary research Introduction: adding comments	Leon	1 hour and 30 min
23-01-2017 | 15:00	Literary research chapter 4, 5 and 8	Eva	2 hours
22-01-2017 | 14:00	Chapter 8	Sofie	1 hour and 30 min
22-01-2017 | 12:00	Chapter 8	Sofie	1 hour
21-01-2017 | 20:00	Finish chapter 7 + start chapter 8	Sofie	3 hours

21-01-2017 | 12:30	Introduction: research question, subquestions, hypothesis Document: solving comments	Leon	2 hours
21-01-2017 | 12:30	Chapter 4 + 5 Graphs	Eva	3 hours and 15 min
10-01-2017 | 10:25	PWS-meeting with mr. Dettmers. Discussed results of experiments; glossary layout; general progress	Eva	50 min
10-01-2017 | 10:25	PWS-meeting with mr. Dettmers. Discussed results of experiments; glossary layout; general progress	Sofie	50 min
10-01-2017 | 10:25	PWS-meeting with mr. Dettmers. Discussed results of experiments; glossary layout; general progress	Leon	50 min
08-01-2017 | 13:30	Chapter 7, chapter 6, meeting, checking, planning	Sofie	8 hours and 30 min
08-01-2017 | 13:30	Chapter 1 Introduction, Chapter 6 Meeting, checking, planning	Leon	8 hours and 30 min
08-01-2017 | 13:30	Chapter 5, chapter 6, meeting, planning	Eva	8 hours and 30 min
06-01-2017 | 13:30	Literary research	Eva	1 hour and 30 min
03-01-2017 | 09:00	Chapter 1	Leon	1 hour
02-01-2017 | 21:30	Chapter 7	Sofie	2 hours and 15 min
02-01-2017 | 12:00	Literary research chapter 1	Leon	30 min
31-12-2016 | 11:30	Literary research chapter 1	Leon	2 hour

31-12-2016 | 10:00	Literary research chapter 1	Leon	1 hour
29-12-2016 | 08:30	Experiment, results	Sofie	7 hours
29-12-2016 | 08:30	Experiment, results	Eva	7 hours
29-12-2016 | 08:30	Experiment, results	Leon	4 hours and 30 min
27-12-2016 | 10:30	Extracting information from Samson Wright's Applied Physiology	Leon	2 hours
20-12-2016 | 10:25	PWS-hour	Leon	50 min
20-12-2016 | 10:25	PWS-hour	Sofie	50 min
20-12-2016 | 10:25	PWS-hour	Eva	50 min
18-12-2016 | 12:00	Execute experiment, meeting, planning	Sofie	5 hours
18-12-2016 | 12:00	Execution experiment, meeting, planning	Eva	5 hours
18-12-2016 | 12:00	Execute experiment, meeting, planning	Leon	5 hours
14-12-2016 | 13:30	Chapter 2: Research, sources Document: Transferring all data	Leon	4 hours and 30 min
14-12-2016 | 12:00	Meeting	Leon	30 min
13-12-2016 | 12:05	Meeting	Eva	25 min
13-12-2016 | 12:05	Meeting	Sofie	25 min
13-12-2016 | 10:25	PWS-hour	Sofie	25 min
12-12-2016 | 19:00	Literary research	Sofie	1 hour and 30 min
11-12-2016 | 13:30	Literary research	Sofie	30 min
29-11-2016 | 20:00	Document: experiment	Leon	1 hour
26-11-2016 | 14:00	Experiment	Leon	3 hours
26-11-2016 | 14:00	Experiment	Sofie	3 hours

26-11-2016 | 14:00	Experiment	Eva	3 hours
21-11-2016 | 19:00	Document and sources	Leon	2 hours
18-11-2016 | 19:00	Literary research chapter 3+4	Eva	1 hour
13-11-2016 | 14:00	Experiment + Literary research	Eva	2 hours
13-11-2016 | 14:00	Experiment + literary research	Sofie	2 hours
13-11-2016 | 14:00	Literary research and experiment	Leon	2 hours
13-11-2016 | 10:15	Literary research and experiment	Leon	3 hours
13-11-2016 | 10:15	Literary research + experiment	Sofie	3 hours
13-11-2016 | 10:15	Literary research + experiment	Eva	3 hours
23-10-2016 | 14:30	Experiment	Sofie	2 hours and 30 min
23-09-2016 | 14:30	Experiment	Leon	2 hours and 30 min
23-10-2016 | 14:30	Experiment	Eva	2 hours and 30 min
22-10-2016 | 12:40	Literary research chapter 4	Eva	40 min
22-10-2016 | 12:00	Experiment: theoretical framework	Leon	1 hour
20-10-2016 | 17:00	Literary research chapter 3	Eva	30 min
15-10-2016 | 13:30	Experiment	Leon	2 hours
15-10-2016 | 13:30	Experiment	Sofie	2 hours
15-10-2016 | 13:30	Experiment	Eva	2 hours
15-10-2016 | 09:30	Literary research question 2 + experiment	Sofie	3 hours
15-10-2016 | 09:30	Literary research chapter 3 Experiment	Eva	3 hours
15-10-2016 | 09:30	Literary research question 1 + experiment	Leon	3 hours

11-10-2016 | 13:00	Literary research: question 1	Leon	2 hours
11-10-2016 | 13:00	Literary research + question 3	Eva	2 hours
11-10-2016 | 13:00	Literary research, subquestion 2	Sofie	2 hours
11-10-2016 | 09:00	Literary research, subquestion 2	Sofie	3 hours
11-10-2016 | 09:00	Literary research question 3 and 4	Eva	3 hours
11-10-2016 | 09:00	Literary research, subquestion 1	Leon	3 hours
10-10-2016 | 12:00	Experiment + literary research	Sofie	4 hours
10-10-2016 | 12:00	Experiment + Literary research	Eva	4 hours
10-10-2016 | 12:00	Experiment + literary research	Leon	4 hours
21-09-2016 | 17:00	Action plan	Sofie	3 hours
21-09-2016 | 17:00	Action plan	Eva	3 hours
21-09-2016 | 17:00	Action plan	Leon	3 hours
15-09-2016 | 11:50	Introduction PWS + explanation on Apprentice	Sofie	40 min
15-09-2016 | 11:50	Introduction PWS + explanation on Apprentice	Eva	40 min
15-09-2016 | 11:50	Introduction PWS	Leon	40 min

Name	Sofie	Eva	Leon
Total amount of hours spent	100 hours and 30 min	96 hours and 39 min	101 hours and 55 min

Word list

Unless the definition is marked with another source, the source is Oxford Dictionaries, retrieved on 01-02-2017 from https://en.oxforddictionaries.com.

Abdomen:	The part of the body of a vertebrate containing the digestive and reproductive organs; the belly.
Adipose tissue:	A type of connective tissue specialized for the storage of fat.
Antibody:	A blood protein produced in response to and counteracting a specific antigen. Antibodies combine chemically with substances which the body recognizes as alien, such as bacteria, viruses, and foreign substances in the blood.
Aortic rupture:	A break or sudden burst of the aorta.
Artery:	Any of the muscular-walled tubes forming part of the circulation system by which blood (mainly that which has been oxygenated) is conveyed from the heart to all parts of the body.
Arteriole:	A small branch of an artery leading into capillaries.
Atherosclerosis:	A disease of the arteries characterized by the deposition of fatty material on their inner walls.
Atrium:	Each of the two upper cavities of the heart from which blood is passed to the ventricles. The right atrium receives deoxygenated blood from the veins of the body, the left atrium oxygenated blood from the pulmonary vein.
Autotrophic:	The ability to form nutritional organic substances from simple inorganic substances such as carbon dioxide.
Axon:	The long thread-like part of a nerve cell along which impulses are conducted from the cell body to other cells.
Bile:	A bitter greenish-brown alkaline fluid which aids digestion and is secreted by the liver and stored in the gall bladder.
Blood clot:	A gelatinous or semisolid mass of coagulated blood.
Blood plasma:	The colorless fluid part of blood in which corpuscles or fat globules are suspended.
BMI:	Body mass index.
Brain hemorrhage:	An escape of blood from a ruptured blood vessel in the brain, especially when profuse.
Capillary:	Any of the fine branching blood vessels that form a network between the arterioles and venules.
Cardiovascular disease:	A disease relating to the heart and blood vessels.
Catheter:	A flexible tube inserted through a narrow opening into a body cavity, particularly the bladder, for removing fluid.
Cell membrane:	The semipermeable membrane surrounding the cytoplasm of a cell.

Cell wall: A rigid layer of polysaccharides lying outside the plasma membrane of the cells of plants, fungi, and bacteria. In the algae and higher plants, it consists mainly of cellulose.

Cerebral circulation: A circulation of the cerebrum of the brain.

Chemothrophy: Any of various forms of nutrition in microorganisms in which energy is derived from the oxidation of simple organic or inorganic chemical compounds without the involvement of light.

Cholesterol: A compound of the sterol type found in most body tissues. Cholesterol and its derivatives are important constituents of cell membranes and precursors of other steroid compounds, but a high proportion in the blood of low-density lipoprotein (which transports cholesterol to the tissues) is associated with an increased risk of coronary heart disease.

Chylomicron: A droplet of fat present in the blood or lymph after absorption from the small intestine.

Cis configuration: A form of geometric or stereoisomerism in which two substituent groups are on the same side of a double bond or aliphatic ring.[148]

Contrast dye: A solution that is used to accentuate specific structures when looking at a body image. Radiocontrast agents are substances that are used in studies such as x-rays, fluoroscopy, and computed tomography (CT) scans. [149]

Coronary Artery Bypass Grafting: A type of surgery that improves blood flow to the heart. [150]

Coronary artery disease: A disease relating to an artery supplying blood to the heart.

Correlation: A mutual relationship or connection between two or more things.

Diastolic pressure: The pressure during the phase of the heartbeat when the heart muscle relaxes and allows the chambers to fill with blood.

Digestive system: The bodily system relating to the process of digesting food.

Double bond: A chemical bond in which two pairs of electrons are shared between two atoms.

Double circulatory system: The system that circulates blood through the body, consisting of the heart, blood vessels and blood.

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[148] Farlex Partner Medical Dictionary. (2012). *cis configuration.* Retrieved on 02-02-2017 from http://medical-dictionary.thefreedictionary.com/cis+configuration

[149] Cluett, J. (24-06-2015). *Contrast dye.* Retrieved on 02-02-2017 from https://www.verywell.com/contrast-dye-2548866

[150] National Heart, Lung and Blood Institute (n.d.) *What Is Coronary Artery Bypass Grafting?.* Retrieved on 02-02-2017, from https://www.nhlbi.nih.gov/health/health-topics/topics/cabg

Duodenum:	The first part of the small intestine immediately beyond the stomach, leading to the jejunum.
Emulsifier:	A substance that stabilizes an emulsion, in particular an additive used to stabilize processed foods.
Endogenous:	Having an internal cause or origin.
Enzyme:	A substance produced by a living organism which acts as a catalyst to bring about a specific biochemical reaction.
Esophagus:	The part of the alimentary canal which connects the throat to the stomach. In humans and other vertebrates it is a muscular tube lined with mucous membrane.
Exogenous:	Having an external cause or origin.
Fatty acid:	A carboxylic acid consisting of a hydrocarbon chain and a terminal carboxyl group, especially any of those occurring as esters in fats and oils.
Genetic:	Relating to genes or heredity.
Haemoglobin:	A red protein responsible for transporting oxygen in the blood of vertebrates. Its molecule comprises four subunits, each containing an iron atom bound to a heme group.
HDL:	High-density lipoprotein: a class of lipoproteins of relatively high density, the main function of which is to transport cholesterol from the tissues to the liver for excretion.
Heart failure:	Severe failure of the heart to function properly, especially as a cause of death.
Heterothroph:	An organism deriving its nutritional requirements from complex organic substances.
Hormone:	A regulatory substance produced in an organism and transported in tissue fluids such as blood or sap to stimulate specific cells or tissues into action.
Hydrophilic:	Having a tendency to mix with, dissolve in, or be wetted by water. The opposite of hydrophobic.
Hydrophobic:	Tending to repel or fail to mix with water. The opposite of hydrophilic.
Hypertension:	Abnormally high blood pressure.
Interesterified fat:	A type of oil where the fatty acids have been moved from one triglyceride molecule to another. This is generally done to modify the melting point, slow rancidification and create an oil more suitable for deep frying or making margarine with good taste and low saturated fat content.[151]

Intermolecular bond: The forces which keep a molecule together.[152]

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[151] Wikipedia. (18-11-2016). *Interesterified fat.* Retrieved on 02-02-2017, from https://en.wikipedia.org/wiki/Interesterified_fat

[152] Wikipedia. (24-01-2017). *Intermolecular force.* Retrieved on 02-02-2017, from https://en.wikipedia.org/wiki/Intermolecular_force

Large intestine: The cecum, colon, and rectum collectively.

LDL: Low-density lipoprotein: a class of lipoproteins of relatively low density, the main function of which is to transport cholesterol to the tissues.

Left ventricular hypertrophy: An enlargement and thickening (hypertrophy) of the walls of your heart's main pumping chamber (left ventricle).[153]

Lipoprotein: Any of a group of soluble proteins that combine with and transport fat or other lipids in the blood plasma.

Lymphatic system: The network of vessels through which lymph drains from the tissues into the blood.

Macrophage: A large phagocytic cell found in stationary form in the tissues or as a mobile white blood cell, especially at sites of infection.

Metabolism: The chemical processes that occur within a living organism in order to maintain life.

Micelle: An electrically charged particle formed by an aggregate of molecules and occurring in certain colloidal electrolyte solutions, as those of soaps and detergents.[154]

Mitochondrion: An organelle found in large numbers in most cells, in which the biochemical processes of respiration and energy production occur. It has a double membrane, the inner layer being folded inward to form layers (cristae).

mmHg: A millimeter of mercury is a manometric unit of pressure.[155]

Myelin sheath: A mixture of proteins and phospholipids forming a whitish insulating sheath around many nerve fibers, increasing the speed at which impulses are conducted.

Nerve impulse: A signal transmitted along a nerve fiber. It consists of a wave of electrical depolarization that reverses the potential difference across the nerve cell membranes.

Osmosis: A process by which molecules of a solvent tend to pass through a semipermeable membrane from a less concentrated solution into a more concentrated one, thus equalizing the concentrations on each side of the membrane.

Pancreas: A large gland behind the stomach that secretes digestive enzymes into the duodenum. Embedded in the pancreas are the islets of Langerhans, which secrete into the blood the hormones insulin and glucagon.

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[153] MayoClinic Staff (n.d.) *Left ventricular hypertrophy.* Retrieved on 02-02-2017, from http://www.mayoclinic.org/diseases-conditions/left-ventricular-hypertrophy/basics/definition/con-20026690

[154] Collins English Dictionary. (n.d.) *Micelle.* Retrieved on 02-02-2017, from http://www.dictionary.com/browse/micelle

[155] Wikipedia. (01-02-2017). *Millimeter of mercury.* Retrieved on 02-02-2017, from https://en.wikipedia.org/wiki/Millimeter_of_mercury

Hydrogenation: A chemical reaction between molecular hydrogen and another compound or element, usually in the presence of a catalyst such as nickel, palladium or platinum. The process is commonly employed to reduce or saturate organic compounds.[156]

Pathogen: A bacterium, virus, or other microorganism that can cause disease.

Percutaneous Coronary Intervention: A non-surgical method used to open narrowed arteries that supply heart muscle with blood.[157]

pH: A figure expressing the acidity or alkalinity of a solution on a logarithmic scale on which 7 is neutral, lower values are more acid, and higher values more alkaline.

Phospholipid: A lipid containing a phosphate group in its molecule, e.g., lecithin.

Photosynthesis: The process by which green plants and some other organisms use sunlight to synthesize foods from carbon dioxide and water. Photosynthesis in plants generally involves the green pigment chlorophyll and generates oxygen as a byproduct.

Phototrophy: Microbial nutrition utilizing light as the chief source of energy.

Plaque: A small, distinct, typically raised patch or region resulting from local damage or deposition of material, such as a fatty deposit on an artery wall in atherosclerosis.

Pulmonary circuit: The path deoxygenated blood takes through the heart to the lungs. [158]

Pylorus: The opening from the stomach into the duodenum (small intestine).

Saturated fat: A type of fat in which the fatty acids all have single bonds.[159]

Small intestine: The part of the intestine that runs between the stomach and the large intestine.

Stent: A tubular support placed temporarily inside a blood vessel, canal, or duct to aid healing or relieve an obstruction.

Sternum: The breastbone.

Sudden cardiac death: A condition in which the heart suddenly and unexpectedly stops beating. If this happens, blood stops flowing to the brain and other vital organs.[160]

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[156] Wikipedia. (25-01-2017). *Hydrogenation.* Retrieved on 02-02-2017, from https://en.wikipedia.org/wiki/Hydrogenation

[157] eMedicineHealth. (n.d.). *What Is Percutaneous Coronary Intervention?.* Retrieved on 02-02-2017, from http://www.emedicinehealth.com/percutaneous_coronary_intervention_pci/article_em.htm

[158] Robson, K. (n.d.). *Pulmonary Circuit: Definition & Pathway.* Retrieved on 02-02-2017, from http://study.com/academy/lesson/pulmonary-circuit-definition-pathway-quiz.html

[159] Wikipedia. (21-01-2017) *Saturated fat.* Retrieved on 02-02-2017, from https://en.wikipedia.org/wiki/Saturated_fat

[160] National Heart, Lung and Blood Institute. (n.d.) *What Is Sudden Cardiac Arrest?.* Retrieved on 02-02-2017, from https://www.nhlbi.nih.gov/health/health-topics/topics/scda

Systemic circuit: The part of the cardiovascular system which carries oxygenated blood away from the heart to the body, and returns deoxygenated blood back to the heart.[161]

Systolic pressure: The maximum pressure occurring in the arteries during a cycle of cardiac contraction and relaxation, which typically occurs near the end of systole.

Thermal conductivity: The rate at which heat passes through a specified material, expressed as the amount of heat that flows per unit time through a unit area with a temperature gradient of one degree per unit distance.

Trans configuration: Denoting or relating to a molecular structure in which two particular atoms or groups lie on opposite sides of a given plane in the molecule, in particular denoting an isomer in which substituents at opposite ends of a carbon–carbon double bond are also on opposite sides of the bond.

Transient ischemic attack: A brief episode of neurological dysfunction resulting from an interruption in the blood supply to the brain or the eye, sometimes as a precursor to a stroke.

Triglyceride: An ester formed from glycerol and three fatty acid groups. Triglycerides are the main constituents of natural fats and oils, and high concentrations in the blood indicate an elevated risk of stroke.

Unsaturated fat: A fat or fatty acid in which there is at least one double bond within the fatty acid chain.[162]

Vasoconstriction: The constriction of blood vessels, which increases blood pressure.

Vasodilation: The dilatation of blood vessels, which decreases blood pressure.

Vein: Any of the tubes forming part of the blood circulation system of the body, carrying in most cases oxygen-depleted blood toward the heart.

Vena cava: Either of two large veins discharging blood into the right atrium of the heart, one conveying blood from the head, chest, and upper extremities and the other conveying blood from all parts below the diaphragm.[163]

Ventricle: Each of the two main chambers of the heart, left and right.

Venule: A very small vein, especially one collecting blood from the capillaries.

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[161] PubMed Health. (n.d.). *Systemic Circulation (Blood Circulation).* Retrieved on 02-02-2017, from https://www.ncbi.nlm.nih.gov/pubmedhealth/PMHT0023062/

[162] Wikipedia. (15-01-2017). *Unsaturated fat.* Retrieved on 02-02-2017, from https://en.wikipedia.org/wiki/Unsaturated_fat

[163] Dictionary.com. (n.d.). *Vena cava.* Retrieved on 02-02-2017, from http://www.dictionary.com/browse/vena-cava