Subject Area(s)
Biology

Associated Unit

Lesson Title

Opening the Arteries

Header

Image 1

ADA Description: The image shows an artist's rendering of the human heart. A strong light shines at one of the left coronary bifurcations, a place that is highly prone to atherosclerotic plaque formation.

Caption: The left coronary artery provides blood to the heart muscle, mainly to the ventricles. The atherosclerotic plaque that forms at the coronary bifurcation from which the left descending and the left circumflex coronary arteries originate is responsible for almost 80% of the deaths that occur as a result of a heart attacks.

Image file: heart.jpg

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Grade Level 10 (9-12)

Lesson # 1of 1

Lesson Dependency
Blood Circulation in One Box

Time Required

50 minutes

Summary

The lesson is designed to introduce students to current clinical treatments of atherosclerotic plaques such as stent deployment (a wire mesh placed inside a clogged artery to open it up) and the tools used by biomedical engineers to analyze the impact of such treatments. The lesson begins with an introduction on atherosclerotic plaques and how they form and develop. The symptoms associated with and the negative impacts that result from the atherosclerotic plaques are described. The stenting procedure is described as the premier treatment option for atherosclerotic plaques. Computational methods used by biomedical engineers to predict and evaluate the impact of placing stents inside diseased arteries are described. Analogies with the use of computational methods in the design or aircraft and racing cars are given.

Engineering Connection

Many computational tools used by engineers in the designing or analysis process are used successfully in the field of biology and medicine. One example is the increase use of computational fluid dynamics to analyze and predict certain aspects of blood flow and the functioning of the cardiovascular system and its parts. Computational studies enable doctors to analyze which treatment is more effective for a specific patient, biomedical engineers to design better medical devices (heart valves, assist pumps, arterial grafts, prosthetic devices, etc.), and biologists to analyze genetic code faster, protein folding and functionality.

Engineering Category = #2

Choose the category that best describes this lesson's amount/depth of engineering content:

1. Relating science and/or math concept(s) to engineering
2. Engineering analysis or partial design
3. Engineering design process

Keywords

Atherosclerosis, biomedical engineering, cardiovascular, carotid, computational fluid dynamics, computational methods, coronary, fluids, heart, heart attack, plaque, stents, stroke

Educational Standards

Biology: Texas Essential Knowledge and Skills (112.34. Biology, Beginning with School Year 2010--2011)

(b) (3) Scientific inquiry. Scientific inquiry is the planned and deliberate investigation of the natural world. Scientific methods of investigation are experimental, descriptive, or comparative. The method chosen should be appropriate to the question being asked.

(c) (2) Scientific processes. The student uses scientific methods and equipment during laboratory and field investigations. The student is expected to:

> (B) know that hypotheses are tentative and testable statements that must be capable of being supported or not supported by observational evidence. Hypotheses of durable explanatory power which have been tested over a wide variety of conditions are incorporated into theories;
>
> (C) know scientific theories are based on natural and physical phenomena and are capable of being tested by multiple independent researchers. Unlike hypotheses, scientific theories are well-established and highly-reliable explanations, but they may be subject to change as new areas of science and new technologies are developed;
>
> (D) distinguish between scientific hypotheses and scientific theories;

(E) plan and implement descriptive, comparative, and experimental investigations, including asking questions, formulating testable hypotheses, and selecting equipment and technology;

(c) (10) Science concepts. The student knows that biological systems are composed of multiple levels. The student is expected to:

(C) analyze the levels of organization in biological systems and relate the levels to each other and to the whole system.

Pre-Requisite Knowledge

Circulatory system components and their function

Learning Objectives

After this lesson, students should be able to:

- Describe the formation and development of atherosclerotic plaques
- Describe the risks associated with plaques such as stroke and heart attacks
- Know what a stent is and how it can be used to treat atherosclerosis
- Describe the negative outcomes of stent placement in arteries such as re-growth of the plaque and blood clotting
- Computational fluid dynamics can be a useful tool in analyzing different stent designs

Introduction / Motivation

Atherosclerosis is a cardiovascular disease that affects millions of people in the U.S. and is one of the leading causes of death in the developed countries. Do you know a family member or a friend that has atherosclerosis or has suffered a cardiovascular event such as a stroke or heart attack and if so can you describe how this affected that person? Have the students describe the outcomes of having a heart attack or stroke. If not, discuss that people who usually had a heart attack or stroke have impaired heart function (in the case of heart attack) or brain function (stroke). Why is that? What happens is that an artery gets blocked and the organs or tissues that are fed with blood from that artery they don't receive blood with oxygen and nutrients and therefore the cells begin to die. In the case of coronary artery blockage the heart muscle cells begin to die while in the case of the brain, it is the nerve cells, the neurons.

Ask students if they know what causes these arterial blockages? Usually they are caused by blood clots but in the case of atherosclerosis it is the atherosclerotic plaque (a deposit of fats, calcium and other macro molecules that are deposited on the arterial wall) that breaks away from the wall and is carried by the blood flow until it reaches a small artery and cannot get through. It is here that a blockage occurs and the blood flow is greatly reduced or stopped. It is similar to the water pipes inside a home, for example pipes from the bathtub or from the kitchen sink that get clogged and require plumbing work. In the case of arteries, if the plaque does not break away and continues to grow it will eventually reduce the blood flow and symptoms will appear such as chest pains (if one of the arteries feeding blood to the heart is constricted) or headaches and nausea (if the arteries feeding blood to the brain are constricted).

Treatments for arteries with plaques include arterial remodeling by balloon or stent implant. Because arteries are flexible, pushing the walls by inflating a small balloon inside the diseased artery can open it up. Ask the students what they think it might happen in the long run after the balloon has been pulled from the artery. A few months after this intervention the flow inside that artery becomes restricted again by the growth of the plaque. An alternative method is to place a cylindrical wire mesh, or a stent, inside the artery over the plaque and expand that mesh such that the artery is open again and normal blood flow rate is restored to normal values. Complications may still appear months after the stent implant as the plaque can re-grow or as blood clots develop. Biomedical engineers are studying the effects of stent placement in the arteries (most stented arteries include the left anterior descending coronary and the carotid arteries) on the blood flow.

Complex engineering is involved behind the design and manufacturing of these small stents as they have to be minimally invasive and have a minimal impact on the arterial wall, be able to hold the artery open and be visible on imaging devices such as computed tomography (X-ray) and magnetic resonance imaging. Computer simulations are routinely used to model physical and biological phenomena, thus helping scientists better understand them. They provide a fast and relatively less expensive alternative to experiments that allows for a huge number of hypotheses to be tested. Scientists and engineers also use computer simulations to design or optimize medical devices, to predict their performance while in use and predict the outcomes of medical procedures or treatments. The computer simulations are nothing else but equation solvers that can solve or estimate the solution to the complex systems of equations that describe physical or biological phenomena. In the case of the blood flow through the arteries it is the equations governing the motion of fluids and of solids (arterial wall) that are solved. These equations have analytical solutions for a few simple flow situations, but for more complex problems like blood flow, no analytical solutions exist, therefore, computers that can solve them through numerical methods are used. These numerical methods have been shown to provide very good solution estimates to complex equations and are used nowadays in every science field. The second activity of this lesson will show some examples of how computer simulations are used to study stent placement.

Lesson Background & Concepts for Teachers

Atherosclerotic plaques (deposits of fat, calcium and other macromolecules) grow on the arterial wall and reduce the amount of blood that can flow through the affected artery and results in diminished delivery of oxygen and nutrients to organs that are fed with blood by the affected artery. The big risk that is associated with atherosclerotic plaques is that some parts of the plaque, or the entire plaques, can rupture (break away) from the wall and then are carried by the stream of blood down the artery. When the piece of plaque enters into an artery with a smaller diameter than its dimensions then that piece of the plaque will block the artery and dramatically reduce or stop the flow of blood. This blockage will result in the damage and eventual death to the organ or the tissue downstream of the clogged artery as the delivery of oxygen and nutrients is stopped. For example, the carotid arteries that deliver blood to the brain can develop atherosclerotic plaques. If the plaque ruptures and the debris from it will block smaller arteries then parts of the brain will not receive fresh blood and this will result in what is popularly known as a stroke. Other risks associated with plaques include blood clot formation (thrombus formation) that can also travel through arteries and block them. Plaque ruptures are responsible for most of the deaths that are due to cardiovascular system diseases.

Detection of plaque formation and development is usually impossible as the disease is asymptomatic and the body can adapt to small changes in blood flow due to relatively small plaques. Most of the people that develop atherosclerotic plaque present symptoms when the plaque is well developed and blocks about 50% or more of the cross-sectional area of the affected artery. Symptoms include headaches and nausea when the cerebral circulation is affected or chest pain when the blood flow to the heart muscle, the myocardium, is affected. Other people, less lucky, they experience strokes or heart attacks without warning as the plaque ruptures.

For people that present early symptoms associated with atherosclerotic plaque and undergo investigation by computed tomography or magnetic resonance imaging to detect the location of the plaque there are surgical procedures that can improve their situation. Doctors perform what is known as angioplasty or arterial remodeling. This procedure consists of a guide wire or catheter that is introduced into the affected artery and a balloon is slowly inflated to expand the section or the artery that has been affected by the growth of the atherosclerotic plaque. However, this is only a temporary solution, as the plaque can continue to grow. A newer solution is represented by the deployment of a wire mesh or stent that is placed over the plaque and then expended such that the artery will regain its normal shape. The stent also acts as a shield that holds the plaque attached to the wall and prevents it from rupturing. Risks involved with stent deployment include the re-growth the plaque over the stent wires and the formation of blood clots. These risks have been lowered recently by the development of drug coated stents. These stents have their wires coated with a layer of drugs that interact with the arterial wall and decrease the re-growth of plaques and blood clot formation.

Computational tools such as computational fluid dynamics are routinely used by scientists and engineers in the design and analysis process. For example, the design of airplanes and the computation of the forces acting on the airplane are nowadays performed by computational fluid dynamics. This enables the testing of different designs in a fast and efficient manner such that the optimal design can be found.

Biomedical engineers are using computational fluid dynamics tools to analyze the function of the cardiovascular system and its components. They also use these tools to predict the impact of certain treatments for cardiovascular diseases. Computational fluid dynamics enable scientists and engineers to analyze the outcome of a treatment without performing an actual surgery or design a complex and expensive experiment. All the analysis is done in the virtual world defined by the laws of physics and theoretical models and implemented through mathematical equation. This allows for a fast and relatively inexpensive method to test different hypothesis and designs for stents and other medical devices such as heart pumps, catheters, arterial grafts, etc.

Image 2

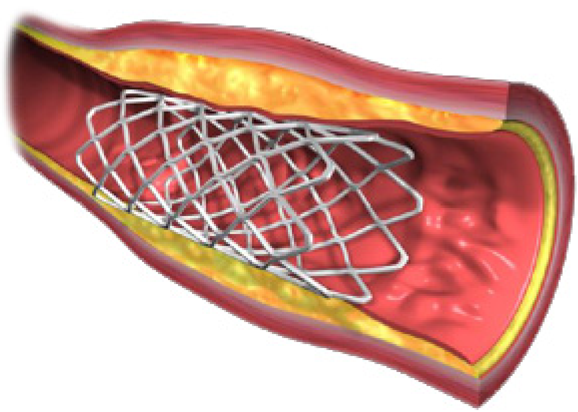

Figure 2

ADA Description: Artist's drawing of an artery with plaque and a stent placed over the plaque in order to open the narrowed artery

Caption: Figure 2. Stents are used to open narrowed arteries by placing them over the atherosclerotic plaque

Image file: stent1.jpg

Image 3

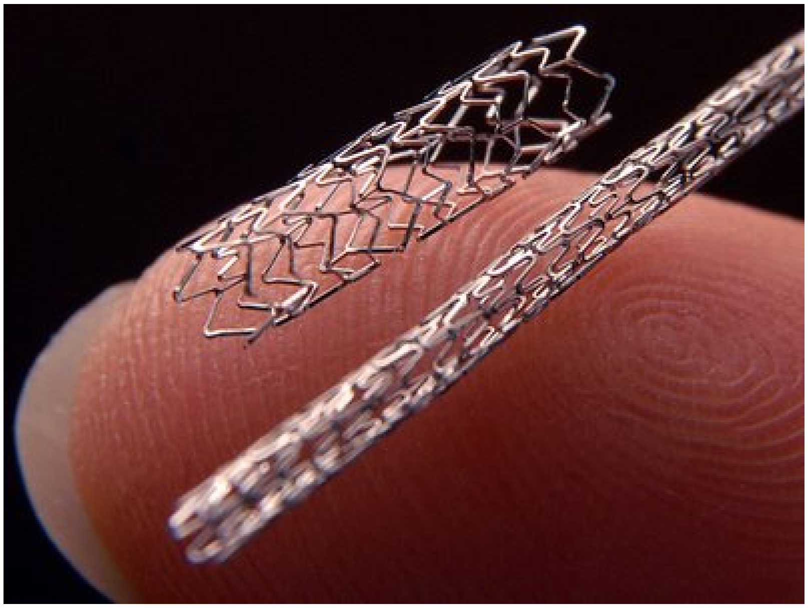

Figure 3

ADA Description: Artist's drawing of an artery with plaque and a stent placed over the plaque in order to open the narrowed artery

Caption: Figure 2. Stents are used to open narrowed arteries by placing them over the atherosclerotic plaque

Image file: stent1.jpg

Vocabulary / Definitions

Word	Definition
Atherosclerosis	The process by which fatty substances, cholesterol, adhesion molecules, monocytes, calcium and other substances build up in the inner lining of an artery.
Coronary arteries	Arteries located on the exterior face of the heart that supply blood to the heart.
Computational methods	A set of methods that are used to find the approximate solution of complex equations that don't have analytical solution.
Endothelial cells	Cells that line the interior surface of blood vessels and are in direct contact with the blood.
Thrombus	Blood clot or the product of blood coagulation.
Stent	A small wires mesh tube inserted in a narrowed artery to hold the artery open.

Associated Activities

The Insider

Virtual blood flow

Lesson Closure

Assessment
See the assessment worksheet attached to this lesson.

Lesson Extension Activities

Additional Multimedia Support

References

Attachments
Lesson_Assessment

Other

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