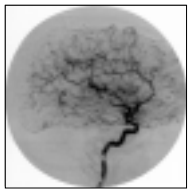
Brain's Blood Supply

Visualizing and measuring blood flow to the brain



Teaching Notes

Overview

Diagnostic medical imaging science has advanced dramatically in recent years. Using radiopaque dyes, physicians are able to visualize blow flow through the body with X-ray images. Image processing techniques are effective tools to analyze medical images, either through image enhancement for better visualization, with measuring tools for quantification, or animation of time-lapse processes. In this lesson, angiograms are analyzed to learn the anatomy of the blood supply to the brain and to discover relationships about vessel size and relative blood flow.

The lesson starts by introducing students to basic image enhancement tools such as false colorization, inversion of pixel values and digital filters to sharpen, shadow and find edges. Students evaluate each of the image enhancement techniques to determine the efficacy of each in helping to make a diagnosis.

In the second part of the lesson, students use the measuring tools to measure the diameter of the aorta and arteries in the neck after reviewing the arterial anatomy of this region. With their data, they calculate the radius, cross-sectional area and resistance for each vessel. After analyzing the data, students infer relationships between vessel size and relative blood flow.

Movement of blood through the brain is visualized with an angiogram. By animating this angiogram, students can track the flow of blood as it moves through the arterial vessels of the head, into the capillaries of the brain, and then into the venous system to drain blood from the head. Students then examine a carotid arteriogram that shows an abnormality which is consistent with increased vascularization in the parietal lobe of the brain, probably due to a tumor. The students are asked to speculate about the probable cause of the increased vascularization in this region.

The lesson culminates with the analysis of a micrograph image of a capillary in the cerebral cortex. The capillary is also measured to determine its diameter, radius, cross-sectional area and resistance. Students then compare the capillary size and resistance with the size and resistance of larger vessels, summarizing the relationships between vessel diameter (radius), cross-sectional area, resistance and blood distribution.

Objectives

Students will:

- use false color, inversion, and filters to evaluate clinical and diagnostic uses of arteriograms.
- review arterial anatomy in the head, neck and chest.
- calculate cross-sectional area and resistance to blood flow in arteries and capillaries to infer relationships between these factors and distribution of blood.

Prerequisites

Prior to this lesson, students should

- be able to describe basic anatomy of the brain.

Goal

Students will investigate angiograms and make measurements to infer relationships between vessel size, resistance to blood flow and blood distribution.

Topics

- Circulatory system
- Brain anatomy and physiology
- Cardiovascular physiology
- Medical imaging

Science Process Skills

- Observation
- Measurement
- Analysis
- Synthesis

IPTechnique Sheets

- Look-Up Tables
- Measuring

Acknowledgments

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Images courtesy of Pima Community College Radiology Department and digitized by Paul Johnson. Angiogram courtesy of University Medical Center, Tucson, Arizona.

Answers

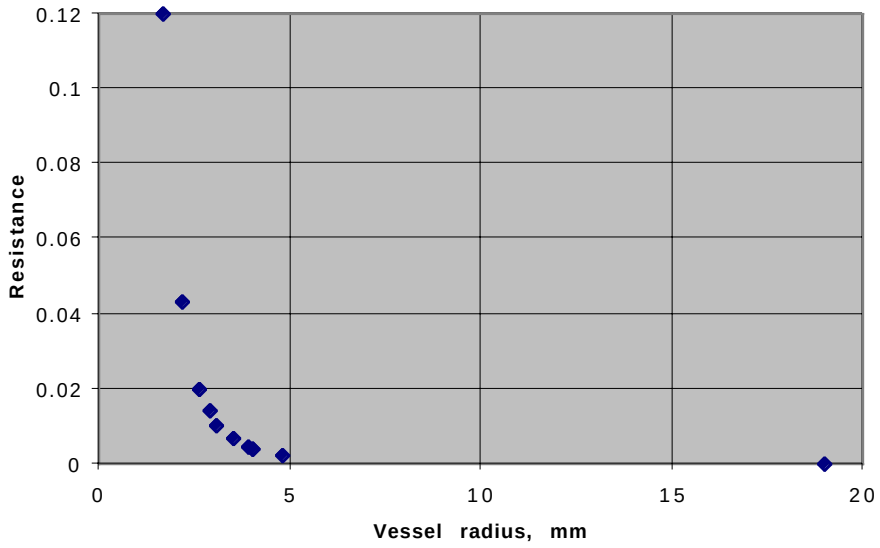
1. The arteries are white because X-rays are absorbed by the radiopaque dye injected into the arteries, preventing exposure of the X-ray film in these areas.
2. Answers will vary. The patient's head is turned to increase exposure of the arteries at the base of the head.
3. The heart is located at the bottom of the image beneath the arch of the aorta. It is represented by the white shadow surrounding the origin of the aorta.
4. Answers will vary according to each student's perception of the image. A color table often allows the human eye to more easily detect differences in pixel values because they can be represented by different colors rather than by similar shades of gray.
5. Answers will vary with each student's ability to see detail in each of the images. Many people see more detail in an inverted X-ray because they have become accustomed to viewing detail with a black-on-white image, such as in a printed page.
6. Answers will vary depending upon which filter is used and how students perceive it to have enhanced the image. A sharpened or shadowed image often makes small details more visible.
7. The internal carotid and vertebral arteries deliver blood to the brain itself.
8. Answers will vary depending upon where each artery is measured and on which arteries are measured. Representative measurements for each of the arteries are shown in the table below.

Artery	Diameter (d), mm	Radius (r), mm (d/2)	Cross-sectional area, mm^2 ($çr^2$)	Resistance ($1/r^4$)
Aorta	38.0	19.0	1134	7.7×10^{-6} or 0.0000077
Right subclavian	8.0	4.0	50.2	3.9×10^{-3} or 0.0039
Left subclavian	6.2	3.1	30.2	1.0×10^{-2} or 0.01
Left common carotid	9.6	4.8	72.3	1.9×10^{-3} or 0.0019
Right common carotid	8.0	4.0	50.2	3.9×10^{-3} or 0.0039
Left internal carotid	7.8	3.9	47.8	4.3×10^{-3} or 0.0043
Right internal carotid	7.0	3.5	38.5	6.7×10^{-3} or 0.0067
Left external carotid	4.3	2.2	15.2	4.3×10^{-2} or 0.043
Right external carotid	3.4	1.7	9.1	1.2×10^{-1} or 0.12
Left vertebral	5.8	2.9	26.4	1.4×10^{-2} or 0.014
Right vertebral	5.2	2.6	21.2	2.0×10^{-2} or 0.02

9. Answers will vary somewhat depending on which vessels students compare the aorta to but should be close to the following values: the aorta is approximately 4 times larger than the common carotid and approximately 7 times larger than the vertebral.
10. Answers will vary as in #8. Representative cross-sectional areas are given in the previous table.
11. Answers will vary depending upon measurements. Representative answers are shown below.

    Estimated % cardiac output by internal carotid arteries: 7.6%

    Estimated % cardiac output by vertebral arteries: 4.2%
12. Answers will vary. Students will need to think about factors such as blood pressure, venous pressure and resistance factors such as friction between the blood and vessel walls, blood viscosity and turbulence to construct their responses.
13. Representative resistance values are given in the table.
14. There is an inverse relationship between vessel radius and resistance, i.e. the larger the vessel radius, the smaller the resistance. Students should construct a graph similar to the one below to diagram this relationship.



15. Answers will vary. The smaller vertebral arteries have greater resistance to blood flow, making students' estimate of blood flow in these arteries greater than what should actually be expected.
16. Slices 1/14 through 6/14 show arterial blood flow, slices 7/14 through 9/14 show capillary perfusion and slices 10/14 through 14/14 show a preponderance of venous blood flow.
17. Gas exchange takes place across the capillary wall by diffusion.
18. Representative measurements are shown in the table below.

Vessel	Diameter (d), μm	Radius (r), μm (d/2)	Cross-sectional area, μm^2 ($çr^2$)	Radius, mm (r in μm/1000)	Resistance ($1/r^4$)
Cerebral cortex capillary	10.5	5.3 μm	88.2	0.0053 mm	1.3×10^9

19. The diameter of a capillary is roughly 1000 times smaller than an artery.
20. A red blood cell is about 7 μm in diameter. The capillary is only about 3 μm larger than this.

21. Answers will vary. The functional significance of the fact that a capillary is only about a third larger in diameter than a red blood cell is that each red blood cell is able to travel next to the capillary wall, allowing diffusion of oxygen and carbon dioxide back and forth between the red blood cell and the tissues surrounding the capillary.

22. Answers will vary depending upon student measurements. Representative measurements and calculations are shown in the previous table.

23. There is an inverse relationship between resistance and velocity of blood flow—the larger the resistance, the slower the velocity of blood flow, and vice versa.

24. Answers may vary. When muscular arterial walls relax, the diameter of the vessels increases, causing a reduction in resistance and an increase in velocity and volume of blood flow. Conversely, when muscular arterial walls constrict, the diameter descreases, causing an increase in resistance and a decrease in velocity and volume of blood flow. The arterial system is thus able to control distribution of blood to various parts of the body.

24. Students should summarize their conclusions based on an analysis of their data. Students should be able to conclude that vessel diameter (or radius) is directly proportional to the cross-sectional area and that resistance to blood flow is inversely proportional to the fourth power of the vessel radius. In a large vessel such as an artery or the aorta, resistance is low and the blood moves fast. In a capillary, which is about 1000 times smaller than an artery, the resistance to blood flow is much higher and thus the blood moves much slower, allowing gas exchange to occur.

More exploration

A. The diameter of the left common carotid is about 8.9 mm and the diameter of the base of the left internal carotid is 11.4 mm. The diameter of the right common carotid is about 7.4 mm and the diameter of the base of the right internal carotid is 8.9 mm.The carotid sinus contains chemoreceptors and baroreceptors that help regulate the blood supply to the brain. When a person has been lying down, the affect of gravity on blood flow is reduced and their blood pressure declines. When they stand up, gravity retards blood flow to the brain, potentially reducing oxygen delivery. Reduced oxygen could cause the person to faint. However, the reduced blood pressure causes the walls of the sinus to "balloon" less, baroreceptors in the wall of the carotid sinus are stimulated less and send fewer impulses to the cardioinhibitory centers in the brain. The heart has reduced impulses from the vagus nerve and the cardiac output increases. Blood pressure increases and the brain's oxygen supply is maintained.

B. The cells of the capillary walls are not visible in this image except for the nuclei which appear purple. The "blood-brain barrier" is mostly a result of the tight junctions between the endothelial cells of capillary walls. There is also a relatively thick basal lamina. These factors prevent blood-borne substances such as metabolic wastes, proteins, toxins and most drugs from moving across the capillary wall into the nervous tissue. However, fat-soluble compounds are not prevented from diffusing across the plasma membrane of the endothelial cells.

C. This is an abnormal arteriogram. Students should observe that there is an area of greatly increased vascularization or the presence of blood in the tissues in the parietal lobe. This increase in vascularization is probably due to a tumor.