Fluids at Rest

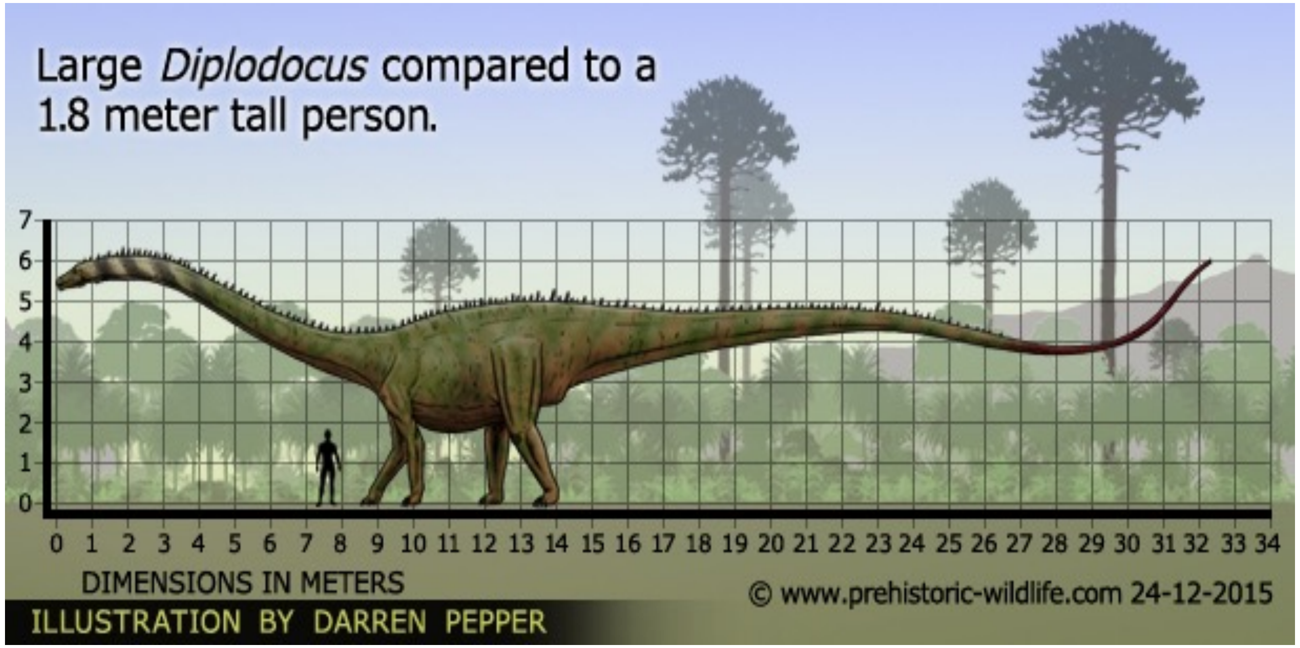
Example 1

The dinosaur *Diplodocus* was enormous, with a long neck and tail and a mass that was large enough to test its leg strength. According to some scientists, *Diplodocus* waded in water, perhaps in water that was up to its head, so that it could use the water to help lighten the load on its legs. To check this idea, let's take the density of *Diplodocus* to be 90% of that of water ($\rho_{water} = 1000\frac{kg}{m^3}$) and assume that the mass of *Diplodocus* was about $1.85\times10^4 kg$ ($\sim 41{,}000 lbs \sim 21 tons$).

If the dinosaur was submerged with 80% of its body under water, what would be the dinosaurs apparent weight? That is, what fraction of the dinosaur's actual weight would be supported?

When it is 80% submerged its lungs would be about $4m$ below the surface of the water. At this depth, what would be the difference in pressure between the water and the dinosaur's lungs?

If, for the dinosaur to breath, the maximum pressure difference needs to be $8000\ \frac{N}{m^2}$ or less, could Diplodocus have breathed submerged in the water?



http://www.prehistoric-wildlife.com/species/d/diplodocus.html

Fluids at Rest

Example 2

Royal Caribbean has some of the largest cruise ships in the world. Consider the Oasis class cruise ship the *Oasis of the Seas* docked at a port. The ship has a weight of $226838tons$ ($\sim 2\times 10^9 N$), is 1184 feet ($\sim 395m$) long, 208 feet ($\sim 69m$) wide, 213 feet ($\sim 71m$) tall and when empty has a maximum draft of $30feet$ ($\sim 10m$), where the draft is how deep the ship can comfortably sink into the water, or how much of the ship is below the water. This ship can accommodate 8461 passengers (6296) and crew (2165).

- Before any passengers and crew get on the ship, what is the draft of the ship?
- Suppose that the ship scheduled to depart and that it is fully laden. How much deeper in the water will the ship sink if all passengers and crew get on the ship for a voyage?

https://en.wikipedia.org/wiki/Oasis_of_the_Seas#/media/File:Oasis_of_the_Seas.jpg

Oasis of the Seas information: https://www.tripsavvy.com/oasis-of-the-seas-royal-caribbean-992876

Fluids in Motion

Example 3:

Consider the airplane shown below. What is the aerodynamic lift produced on the wing if the wing has a surface area $A_{wing} = 60m^2$ and the velocity of the airflow across the top and bottom of the wing are $340\frac{m}{s}$ and $290\frac{m}{s}$ respectively?

Fluids in Motion

Example 4:

Consider a dam, like the O'Shaughnessy Dam in California, shown on the right. The dam holds back a reservoir of water.

Let the reservoir have a cross-sectional area A_{top} and someone opens a flood gate on the face of the dam at a depth d below the surface of the water in the reservoir. The flood gate has an area A_{fg} defined by its radius $r_{fg} = 1.7m$ $(\sim 5ft)$.

What is the speed of the water flowing out of the floodgate on the side of the dam if $d = 10m$?

https://en.wikipedia.org/wiki/O%27Shaughnessy_Dam_(California)

Fluids in Motion

Example 5:

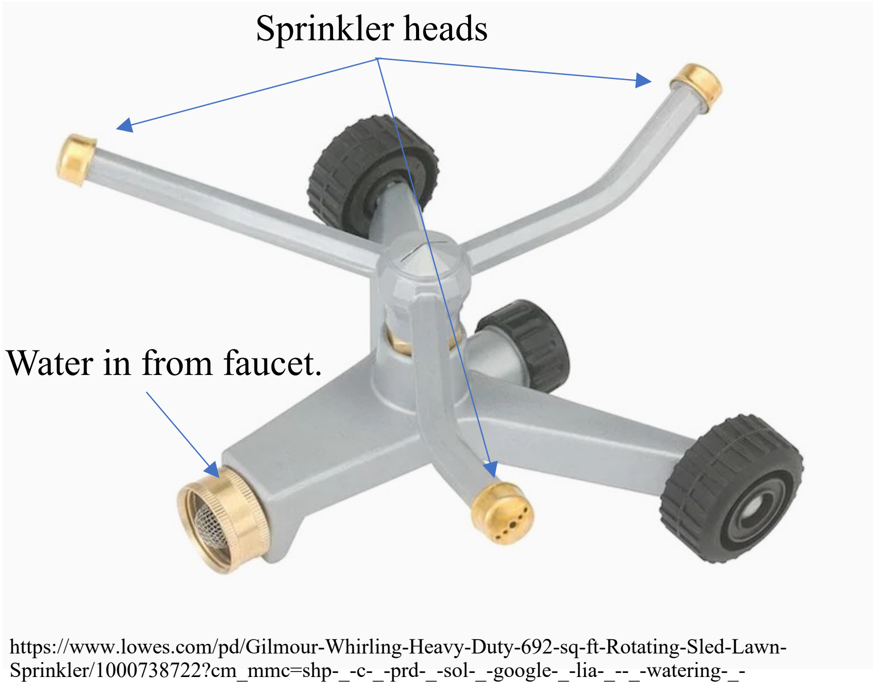
A lawn sprinkler is being fed by a hose with a diameter of $0.019m$ ($\sim\frac{3}{4}$"). The flow rate for the water in the hose from a faucet at the house is $6.31\times10^{-5}\frac{m^3}{s}$ and the water ultimately flows out of three cylindrical sprinkler heads each with a diameter of $0.0064m$ ($\sim\frac{1}{4}$"). In the figure, ignore the "gold" looking ends and assume the water exits through one circular opening at the end of each sprinkler head.

- What is the speed of the water as it enters the sprinkler from the hose?

- What is the speed of the water as it exits from one of the sprinkler heads?

- The outflow from the sprinkler creates a torque about the center of the sprinkler and this distributes water to the lawn. If the water is turned on and the sprinkler spins at a finale rate of $\omega = 61\frac{rev}{min}$ after a time of $t = 3s$, what is the radius of the sprinkler and what are the tangential and angular accelerations of the sprinkler heads?

- What torque was produced the water flowing out of the sprinkler heads and what force was exerted on the sprinkler heads by the exiting water?



https://www.lowes.com/pd/Gilmour-Whirling-Heavy-Duty-692-sq-ft-Rotating-Sled-Lawn-Sprinkler/1000738722?cm_mmc=shp-_-c-_-prd-_-sol-_-google-_-lia-_--_-watering-_-1000738722-_-0&store_code=1740&placeholder=null&gclid=EAIaIQobChMIlL7M277F6QIVDNvACh1P5gIDEAQYBiABEgLUCvD_BwE&gclsrc=aw.ds

Rotational and Translational Statics

Example 6:

As high as eighty percent of the population at one time or another will suffer from some form of lower back pain, especially during bending and lifting activities.

The stresses, which the mussels apply to the disks located between each of the vertebrae, can be very large and these stresses can, along with degeneration of the structure of the disks produce pain, muscle spasm, and immobilization of the lower back. We'll specifically look at the lumbo-sacral intersection of the spine as the point at which we bend, to say pick something up when you keep your legs straight.

We'll look at a specific case of just bending over with your arms hanging vertically to determine how large the reaction force on the lumbo-sacral disk can be in this case in terms of your weight.

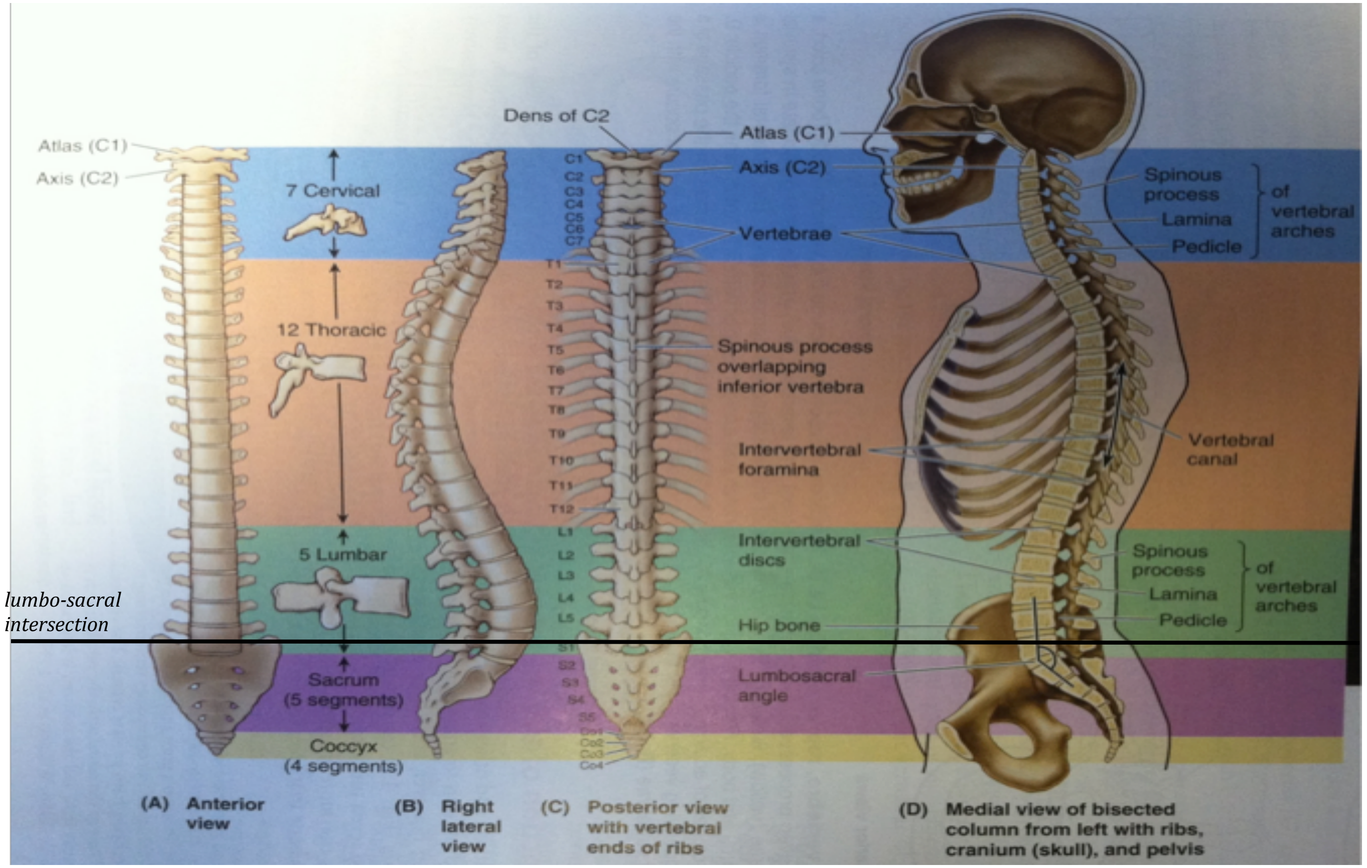


Figure 1: Views of the human spine. Figure from Clinically Oriented Anatomy, by Morre & Dalley.

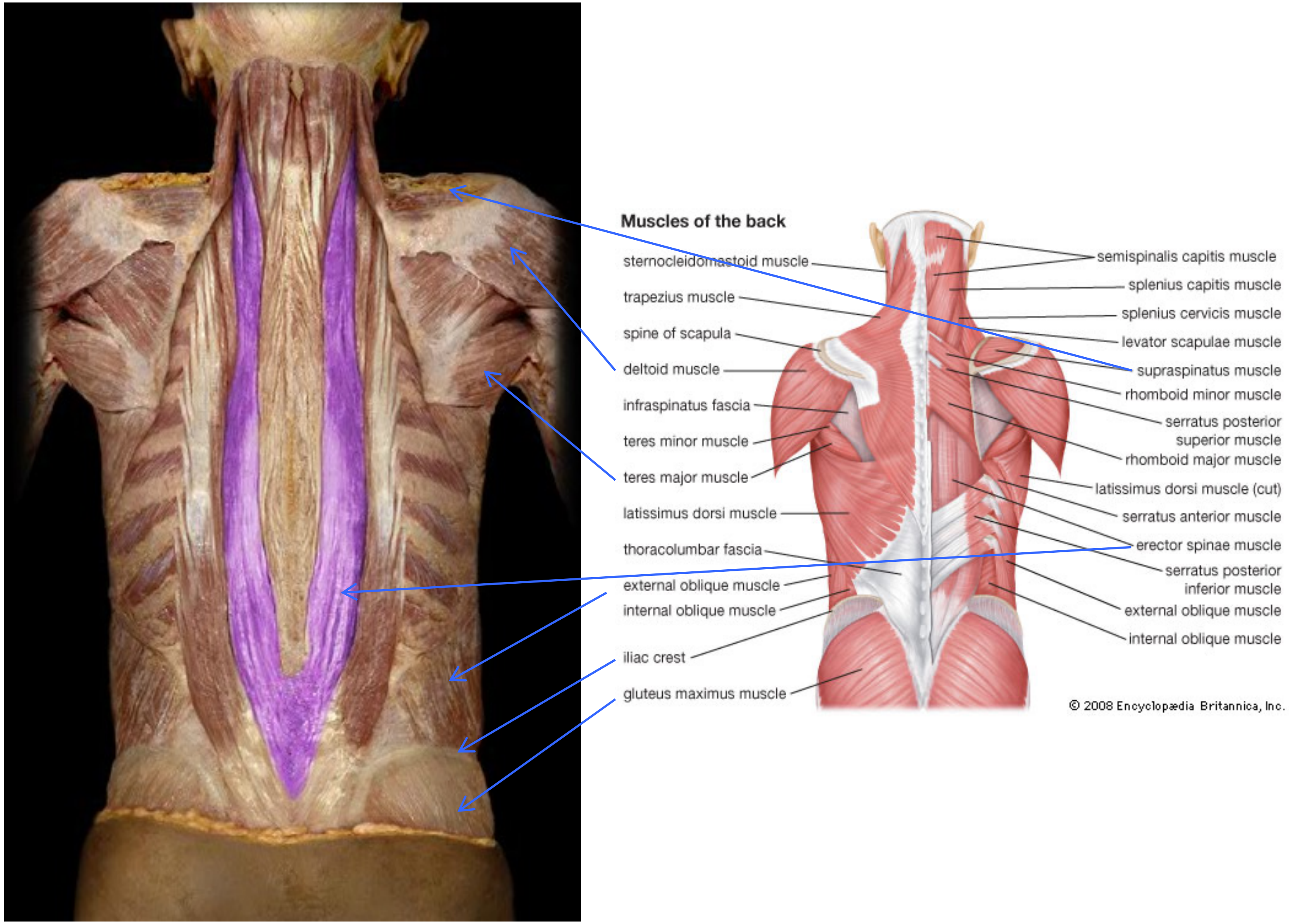
Rotational and Translational Statics

Example 6: - *The Major Muscle Groups and Vertebral Column of the Human Back*

Cadaver dissection showing the location of the *erector-spinae* muscles (stained purple for visualization).

The major muscle groups and muscles of the back are also shown.

The *erector-spinae* muscles insert at the base of the spine and run the length of your spinal column. These muscles are, in part, responsible for picking you back upright (making your erect) from a prone (or bent over) position.



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Rotational and Translational Statics

- The Major Muscle Groups and Vertebral Column of the Human Back

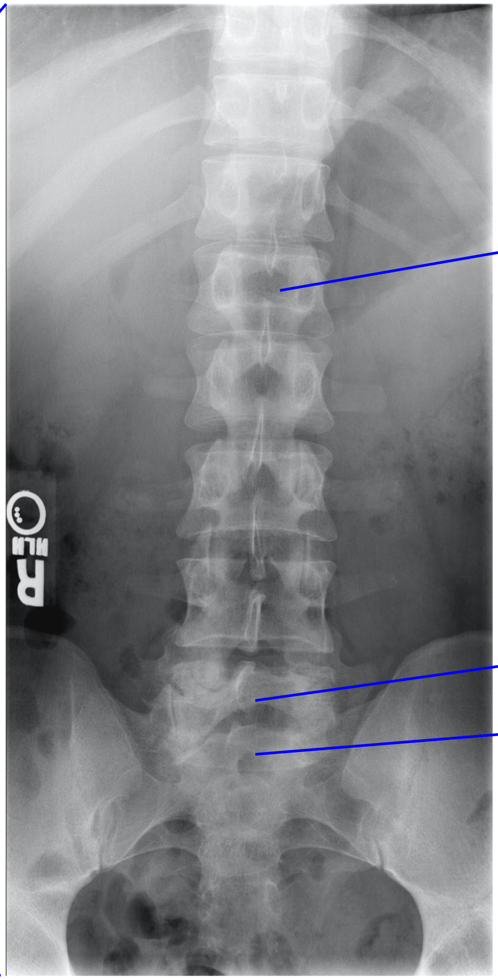
Example 6:

Cadaver dissection showing the location of the *erector spinae* muscles groups on either side of the spine and the vertebra of the spine.

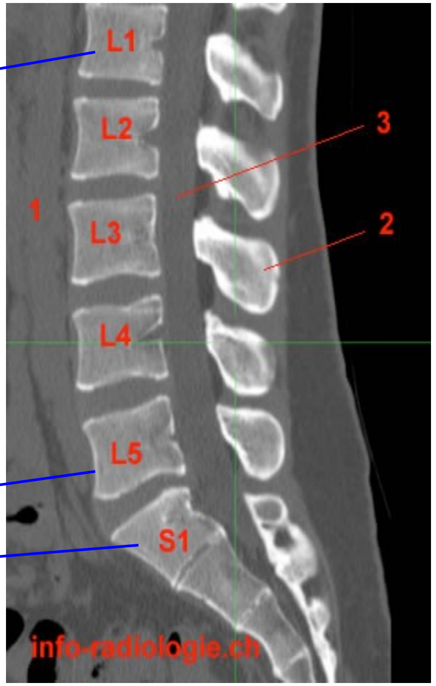
Here it's been superimposed an x-ray image of the spine onto the back showing the erectors lie just to the side of the spinal column.

The magnetic resonance (MRI) image of the spinal column show the location of interest at the L5/S1 intersection. This is the disk (between the vertebra) that is often ruptured by lifting heavy loads incorrectly.

https://www.studyblue.com/notes/note/n/huaty-1223-study-guide-2011-12-rooney/deck/9730325



http://medicine.missouri.edu/radiology/iCases/MSK/case1/case01.htm



http://w-radiology.com/ct-lumbar-spine.php

Rotational and Translational Statics

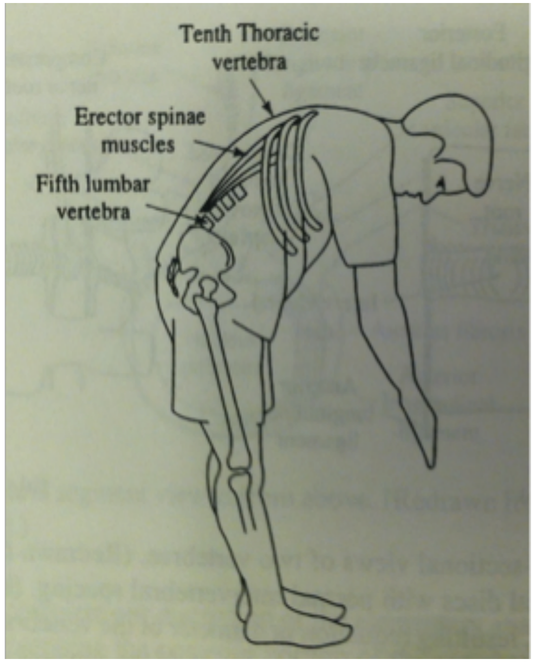
Example 6:

- What are the expressions for the sum of the forces in the vertical and horizontal directions?

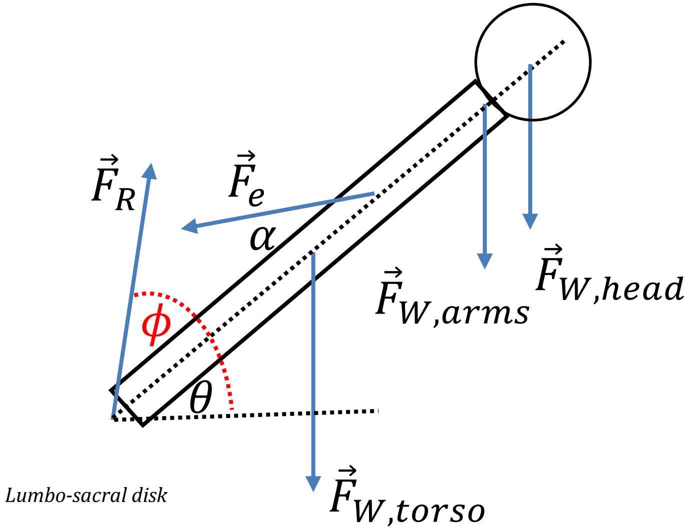
- What is the expression for the sum of the torques about the lumbo-sacral disk? We'll assume that you have bent over so that your spinal column makes an angle θ with respect to the horizontal and are not moving.

- What is the magnitude of the force F_e exerted by the *erector spinae* muscles at a point two-thirds the length (L) of your spine? Assume that $\theta = 30^0$, $\alpha = 12^0$, $F_{W,torso} = 0.5F_W$, $F_{W,arms} = 0.1F_W$ and $F_{W,head} = 0.07F_W$.

- What is the magnitude and direction of the reaction force F_R at the base of the spine, or at the lumbo-sacral joint, in terms of your weight F_W?



Cartoon illustration of the problem.
Drawing from *Physics with Illustrative Examples from Medicine and Biology*, by Benedek & Villars.

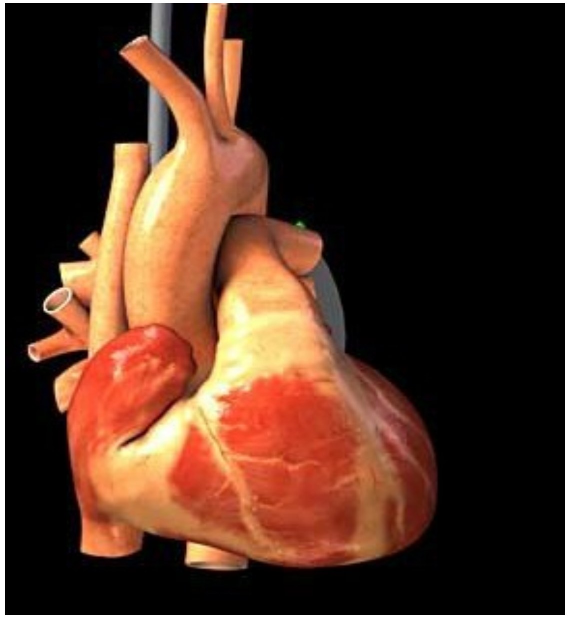


Stick figure drawing of your spinal column showing the various forces that act. The diagram is not to scale

The Physics of the Body

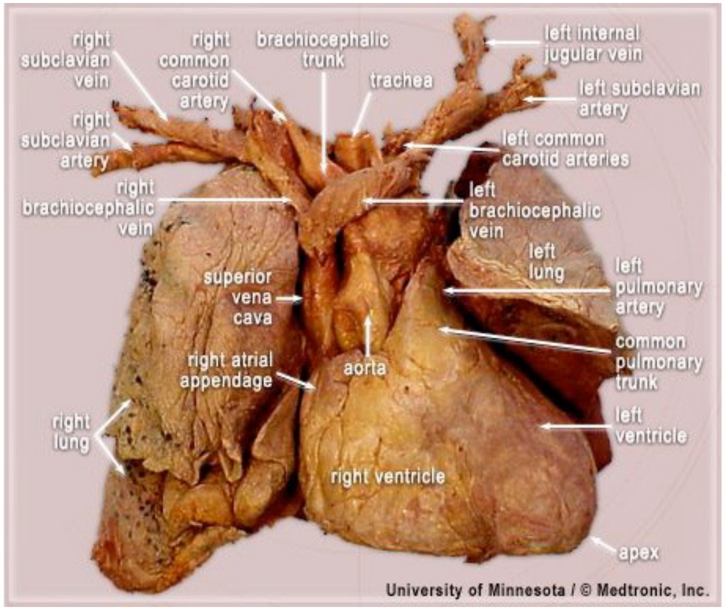
- The Human Heart

The human heart is a dual suction/pressure pump that pulls in blood from the major systems of the body and pumps blood back out to those major systems through a closed loop.



A schematic of the left of the human heart and a cadaver dissection of the human heart and lungs on the right showing part of the circulatory system.

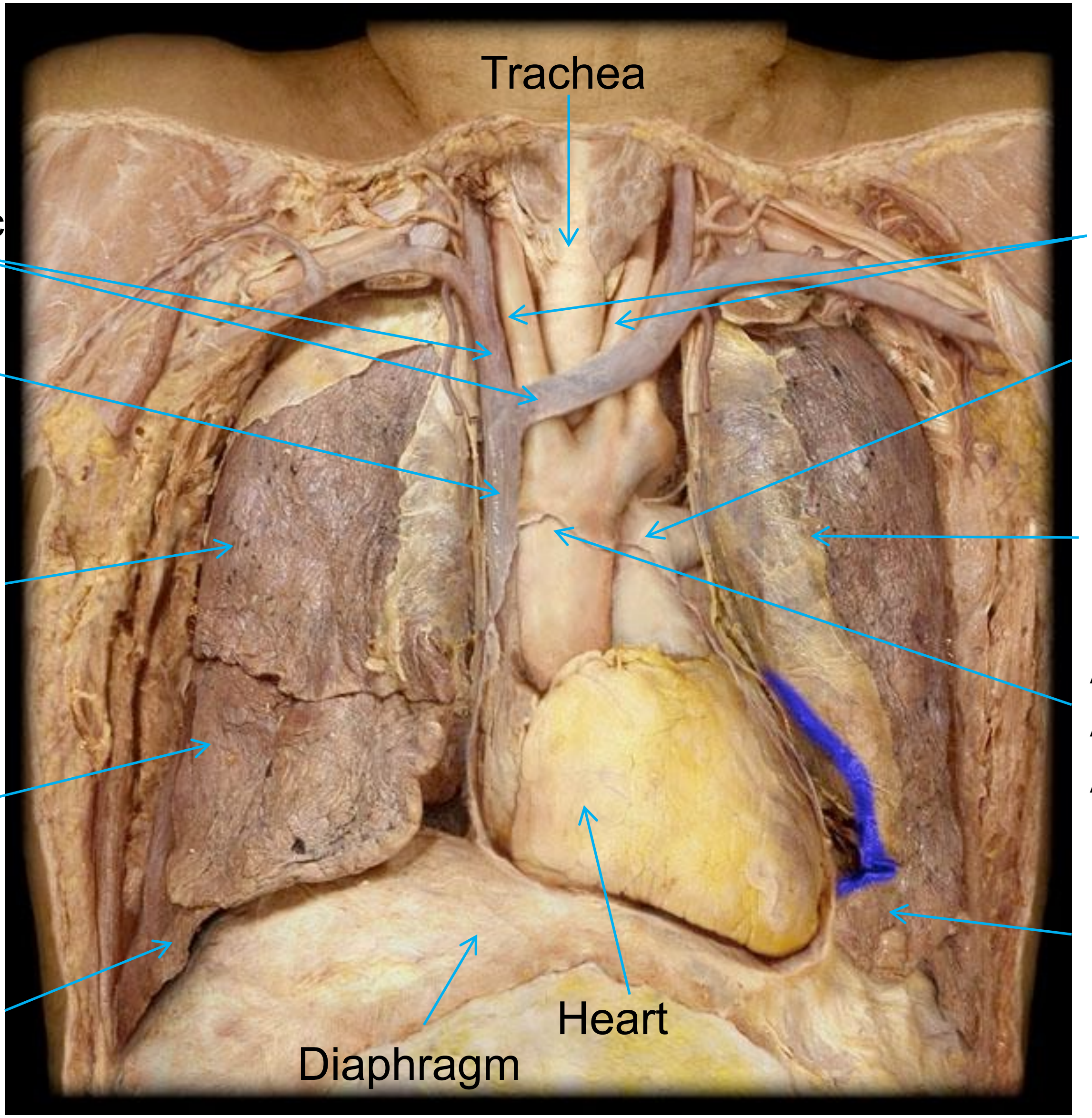
The atria of the heart provide suction to pull blood in from the systems of the body while the ventricles provide pumping to push the blood around to the systems of the body.



The function of the heart is to pump blood through the network of arteries and veins called the cardiovascular system.

Arteries carry oxygenated blood from the heart to the major systems of the body and veins carry oxygen poor blood back to the heart.

The Human Heart

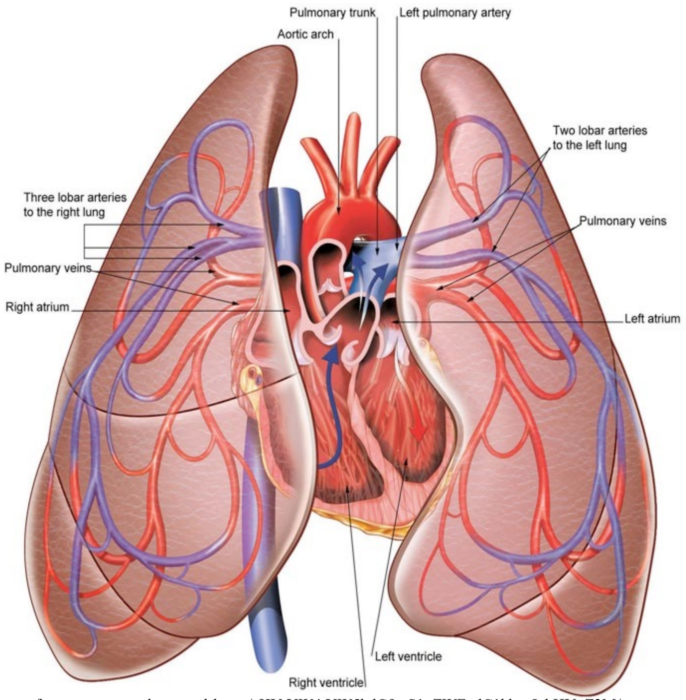


Anatomical view of a cadaver dissection of the thoracic (or chest) cavity.

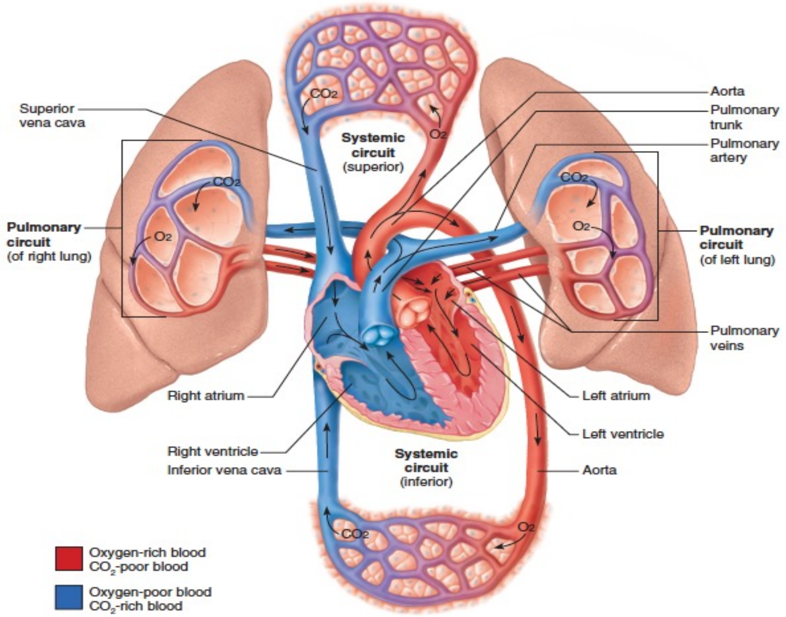
This shows the major organs in the chest and upper abdomen of the human body.

The Human Heart

- Cartoon diagrams showing the major anatomical locations of the heart and lungs showing the relation to major arteries/veins.



http://www.stylepinner.com/human-anatomy-heart-and-lungs/aHVtYW4tYW5hdG9teS1oZWFydC1hbmQtbHVuZ3M/



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The heart and lungs form a closed loop system of which forms the basis for the circulatory system.

The Human Heart

Blood flows from the systems of the body into the right atrium where it is pushed into the right ventricle.

The blood that enters the right side of the heart from the superior (above) and inferior (below) vena cava is oxygen poor.

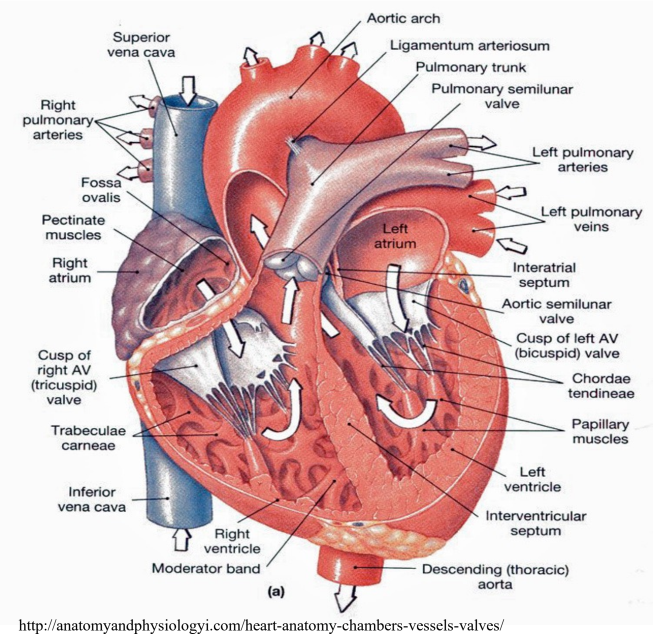
The blood is pumped from the right ventricle through the left and right pulmonary arteries to the lungs where carbon dioxide is exchanged for oxygen in the blood.

The oxygen rich blood is pulled into the left atria from the pulmonary veins and into the left ventricle.

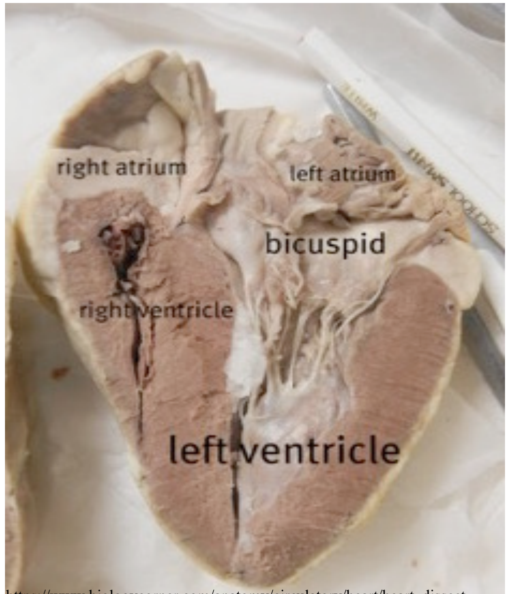
The left ventricle pumps the blood out through the aorta which ascends and splits into the carotid arteries into the head, neck and face and descends into the femoral arteries in the legs.

The blood flows from the arteries to the veins by passing through capillary beds of the major organs.

Valves in between the atria and ventricles control the blood flow so that it flows in only one direction (no regurgitation from the ventricles back into the atria.)



http://anatomyandphysiologyi.com/heart-anatomy-chambers-vessels-valves/



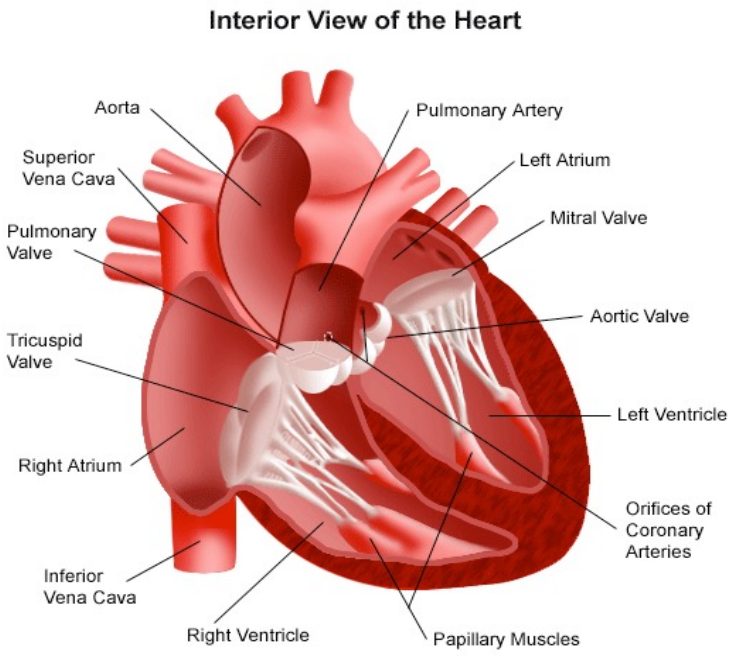
https://www.biologycorner.com/anatomy/circulatory/heart/heart_dissection.html

The Human Heart

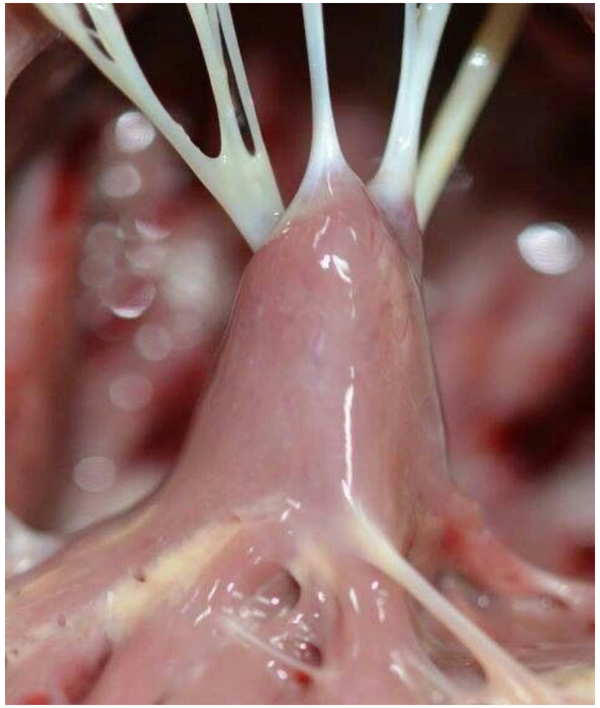
The *Chordae Tendineae* (or heartstrings) are strong, fibrous strings attached to the leaflets (or cusps) of the heart on the ventricular side; i.e., the lower chamber.

These strings originate from small mounds of muscle tissue, the *papillary muscles*, which project inward from the walls of the ventricle.

The heartstrings anchor the valves and aid in their opening/closing.



http://vector.childrenshospital.org/2012/10/new-valves-for-babies-that-can-grow-with-them/

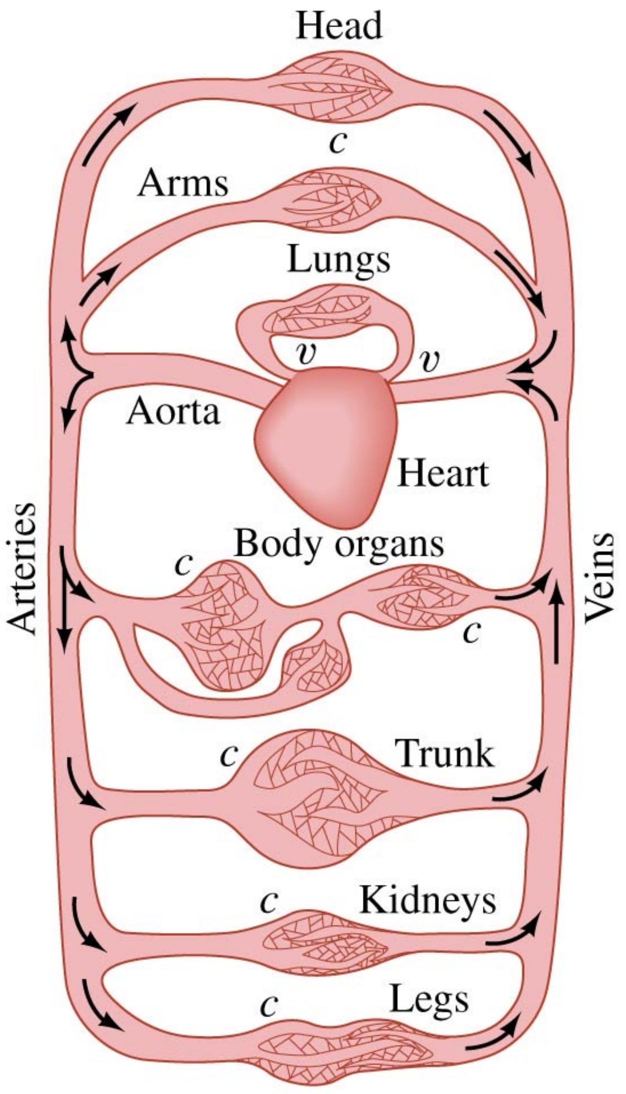


The Human Heart

Example 7:

Suppose that the aorta has an average radius of about $r_{aorta} = 1.25cm$ and the typical average blood velocity $11\frac{cm}{s}$ with an average density of $\rho_{blood} = 1050\frac{kg}{m^3}$. The human circulatory system is a closed loop system, so the flow rate of blood out of the heart has to be the same as the flow rate of blood coming back to the heart.

- What is the total flow rate of blood through the aorta?
- What is the average blood velocity in the major arteries if the total cross-sectional area of the major arteries is $20cm^2$?
- On the assumption that all the blood in the circulatory system goes through the capillaries, what is the total cross-sectional area of the capillaries if the average velocity of the blood in the capillaries is $0.03\frac{cm}{s}$?
- If a typical capillary has a cross sectional area of $3\times10^{-11}m^2$, about how many capillaries are there in the human body?
- If a capillary has an average length of $l = 0.75mm$ what is the average time that a red blood cell spends in a capillary?



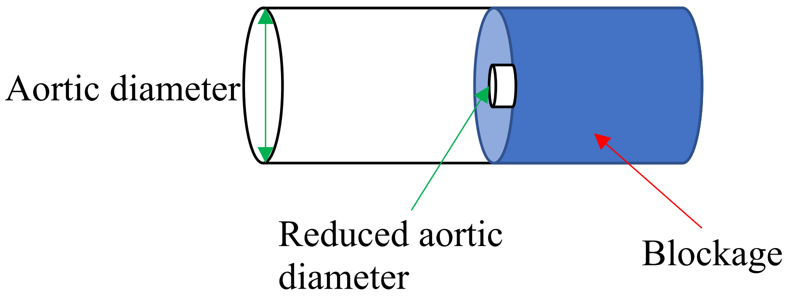
v = valves
c = capillaries

The Human Heart

Example 8:

The human heart can be modeled as a mechanical pump. The aorta is a large artery ($r_{aorta} = 1.25cm$) that carries oxygenated blood ($\rho_{blood} = 1050\frac{kg}{m^3}$) away from the heart to the systems of the body. A typical flow rate for blood out of the heart is $3\times10^{-3}\frac{m^3}{min}$ and the heart does work (with every beat) at a rate of $0.5\frac{mJ}{s}$. A condition associated with arteries in the human body is Atherosclerosis . Atherosclerosis is a disease in which plaque builds up inside your arteries. Arteries are blood vessels that carry oxygen-rich blood from your heart and other parts of your body. Plaque is made up of fat, cholesterol, calcium, and other substances found in the blood. Over time, plaque hardens and narrows your arteries. This limits the flow of oxygen-rich blood to your organs and other parts of your body. Atherosclerosis can lead to serious problems, including heart attack, stroke, or even death.

- What is the expression for the energy per unit volume for blood flowing in the aorta?
- What is the expression for the power produced by the heart in terms of the flow rate of blood out of the heart and the energy per unit volume of blood flowing in the aorta?
- What is the radius of the blockage in the aorta?
- What percent of the aorta is blocked?



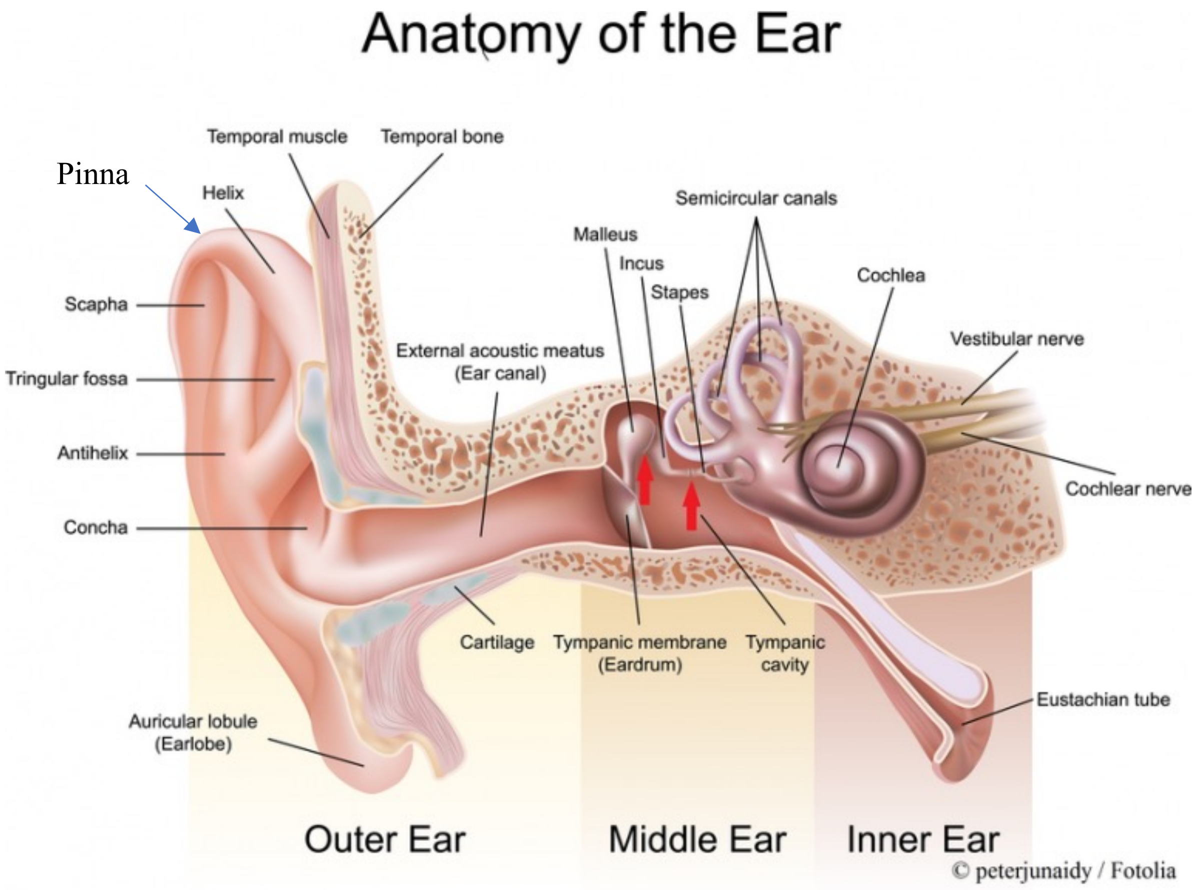
The Human Ear

The human ear is the organ for channeling and detecting sounds in nature. Hearing is produced by the response of nerves in the ear to pressure variations in the incident sound waves. The nerves in the ear are more sensitive to pressure variations than other parts of the body (the skin for example.)

The ear is divided into three main sections.

The outer ear which is composed of an external flap called the *pinna* and the ear canal. The ear canal ends at the *tympanic membrane* (or the eardrum.) In some animals the pinna is large and can be rotated towards the sounds source (in your dog or cat for example). In humans this doesn't seem to help with hearing.

The ear canal of an average adult is $0.75cm$ in diameter and $2.5cm$ long.



https://www.onlinebiologynotes.com/human-ear-structure-anatomy/

The ear is sensitive to frequencies ranging from $20s^{-1}$ to $20000s^{-1}$, with the ear canal resonant for frequencies around $3000s^{-1}$

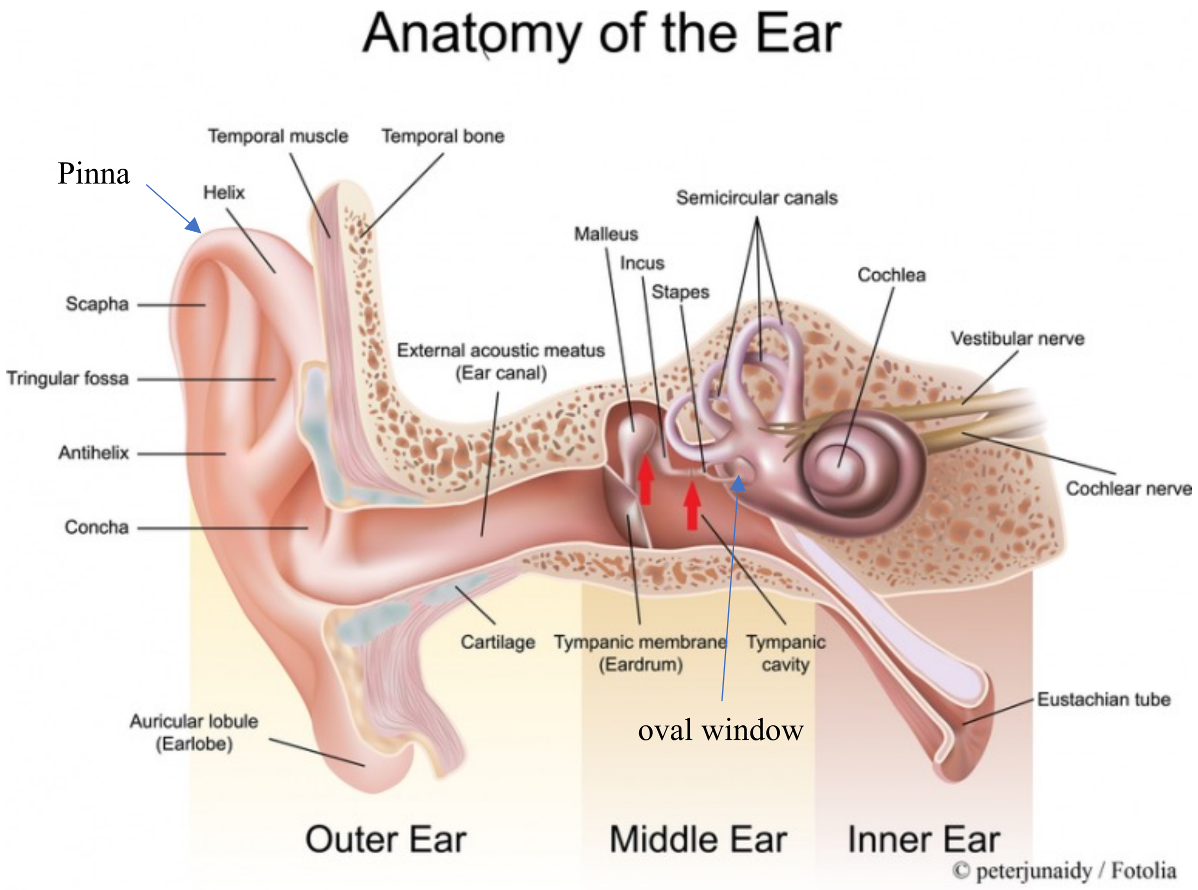
The Human Ear

The middle ear is an air-filled cavity that contains a linkage of three bones called *ossicles* that connect the tympanic membrane to the inner ear.

These three bones are the *Malleus* (hammer), *Incus* (anvil), and the *Stapes* (stirrup). The hammer is attached to the inner surface of the eardrum while the stirrup is connected to the oval window, which is the membrane covered opening to the inner ear.

When sounds are incident on the eardrum, the vibrations induced are transmitted to the hammer/anvil/stirrup which produces pressure variations in the inner ear

The purpose of the outer and middle ear is to channel the sounds into the inner ear where they are turned from pressures into electrical signals that go to the brain.



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The Human Ear

The inner ear is composed of the cochlea and the cochlear nerve.

The cochlea coverts the pressure waves from the sound into electrical signals which are transmitted to the brain by the cochlear nerve.

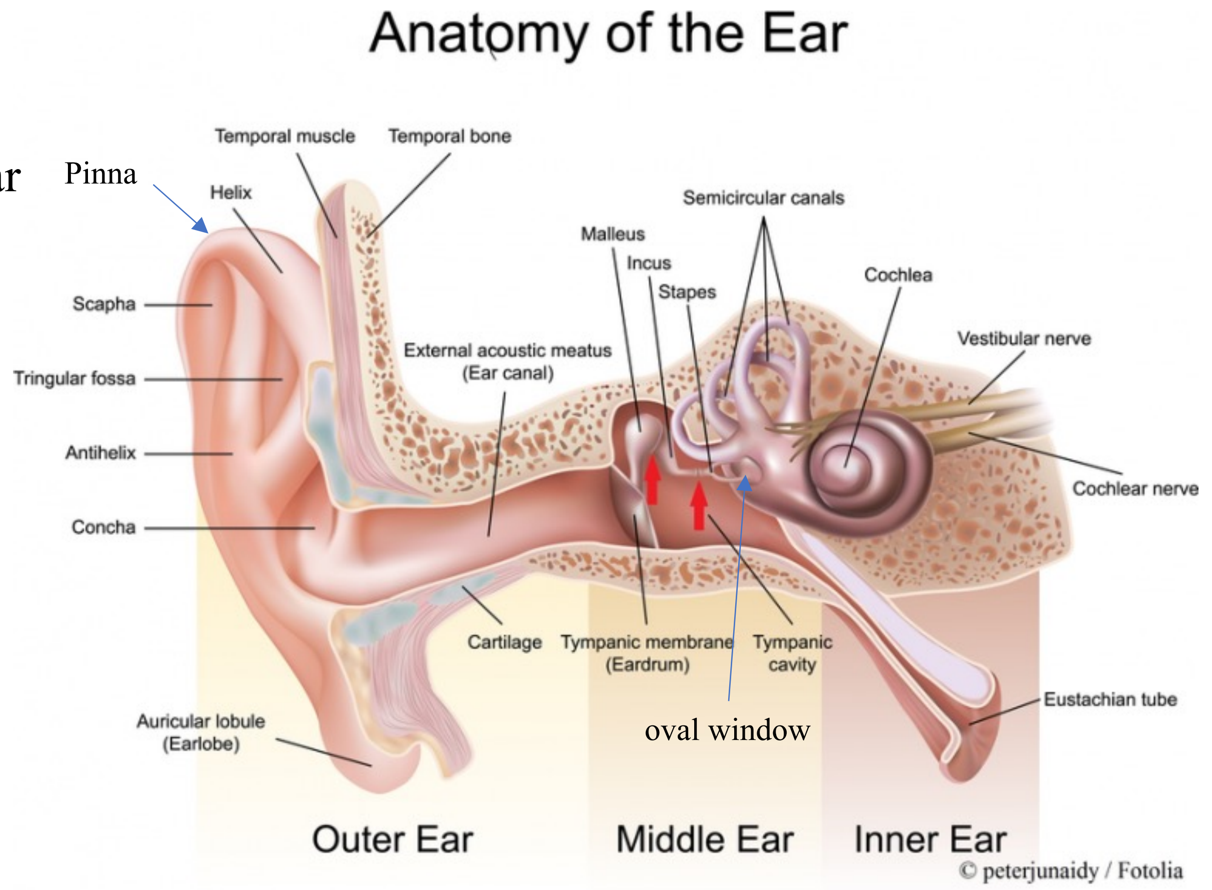
The cochlea is a spiral cavity with an area of about $4mm^2$ and an uncoiled length $35mm$.

The cochlea is filled with fluid and vibrations of the oval window set up a sound wave traveling in the cochlear fluid.

The human ear is sensitive to intensities in the range of $1\times 10^{-12}\frac{W}{m^2}$ (the threshold of hearing) to $1\frac{W}{m^2}$ (pain).

How many decibels do the threshold of hearing and pain correspond to?

If your ear responds to a sound that has an intensity at the threshold of hearing, what is the pressure variation in the cochlea due to this sound?



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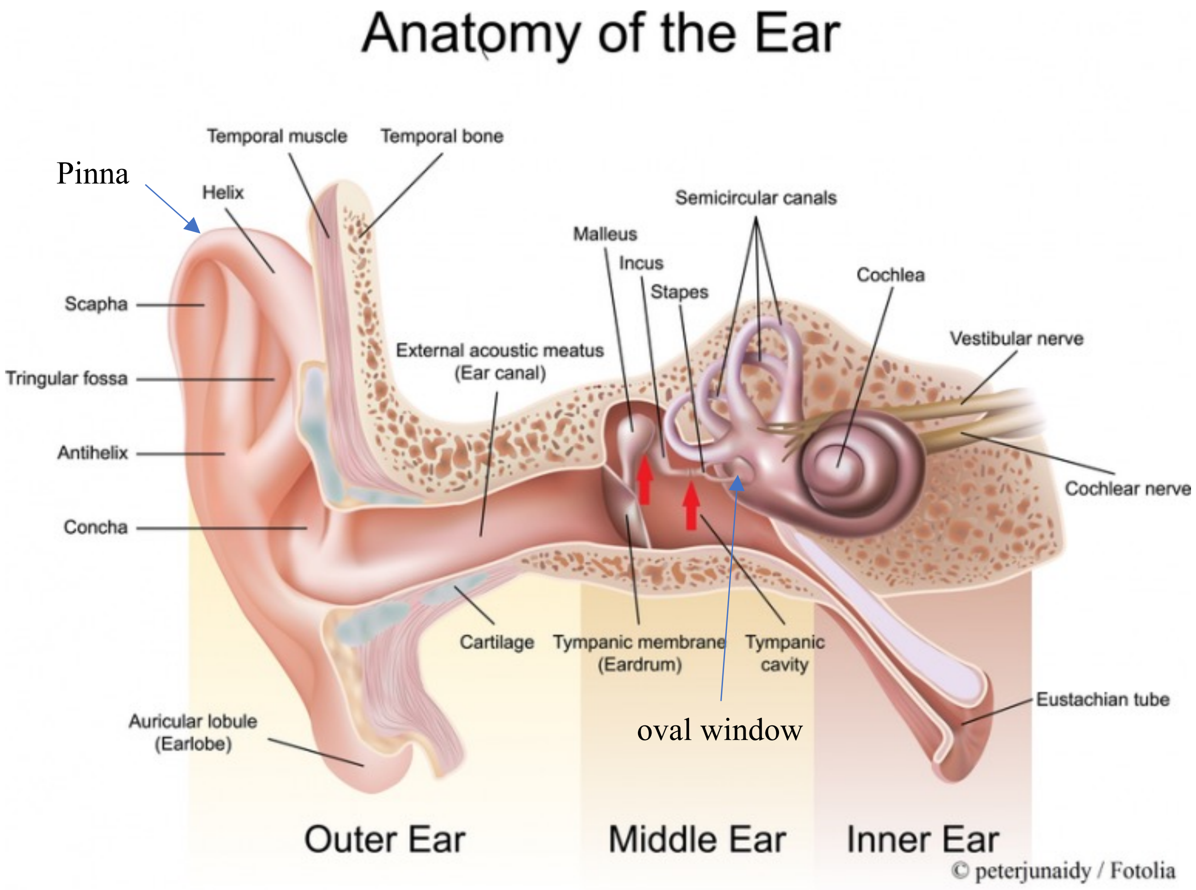
The Human Ear

At the threshold of hearing what is the displacement of the air molecules? At the threshold for pain?



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