Fluids in humans

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2025 W48[1]

[1]Phys 20.01 Mod 5. All figures are from Urone (2022), Hewitt (2024), Young and Freedman (2019) unless noted.

Agenda

Previously

Pressures in the body

Buoyancy of the body

Quiz time 🕐

Previously

Fluid flow, Bernoulli's, viscosity, turbulence

Pressures in the body

Blood pressure 🫀

- Next to taking a person's temperature and weight, measuring blood pressure is the most common of all medical exams
- The pressures in various parts of the body can also be measured and often provide valuable medical indicators

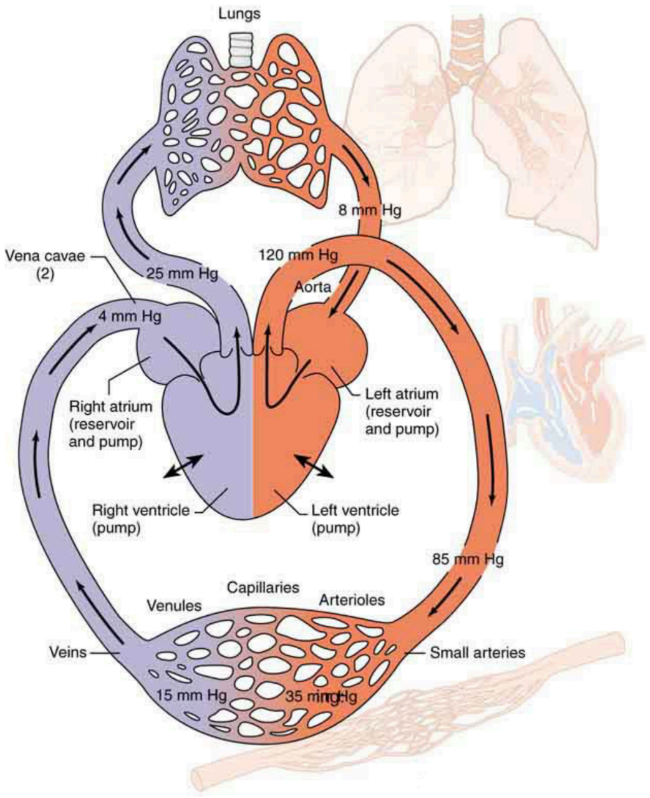
Body system	Gauge pressure in mm Hg
Blood pressures in large arteries (resting)	
Maximum (systolic)	100–140
Minimum (diastolic)	60–90
Blood pressure in large veins	4–15
Eye	12–24
Brain and spinal fluid (lying down)	5–12
Bladder	

Body system	Gauge pressure in mm Hg
While filling	0–25
When full	100–150
Chest cavity between lungs and ribs	−8 to −4
Inside lungs	−2 to +3
Digestive tract	
Esophagus	−2
Stomach	0–20
Intestines	10–20
Middle ear	<1

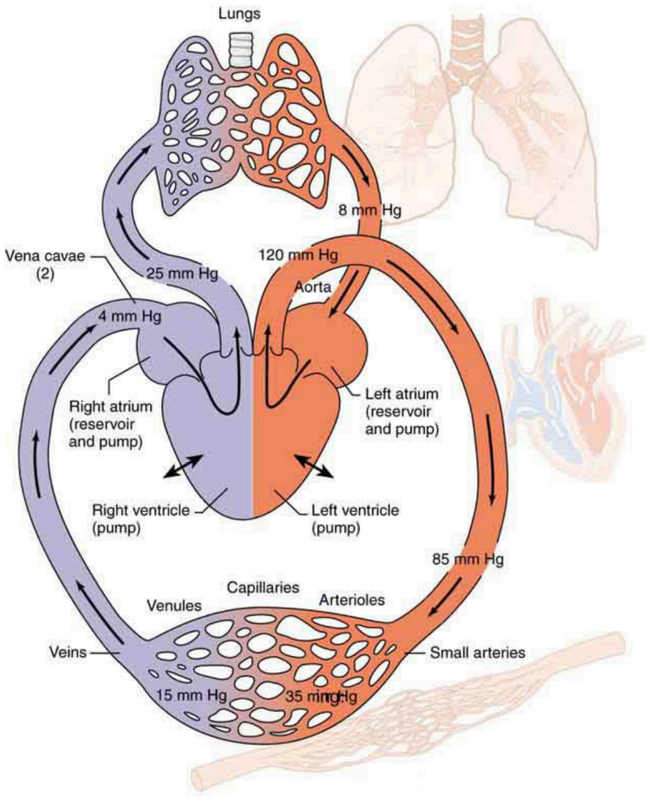
- Blood pressure pulsates because of the pumping action of the heart, reaching a maximum called **systolic pressure**, and a minimum called **diastolic pressure**, with each heartbeat
- The first pressure is representative of the maximum output of the heart. The second is due to the elasticity of the arteries in maintaining the pressure between beats
- When systolic pressure is chronically high, the risk of stroke and heart attack is increased. If it is too low, fainting is a problem

- Diastolic can be an indicator of fluid balance
  - When low, it may indicate internal hemorrhaging and the need for a transfusion
  - When high, it may indicate a ballooning of blood vessels, which may be due to the transfusion of too much fluid into the circulatory system, or due to blood vessels not dilating properly to pass blood through
- Only aortal or arterial BP can be measured non-invasively. Others can be measured invasively using thin tubes called **catheters**, which are threaded into the location of interest

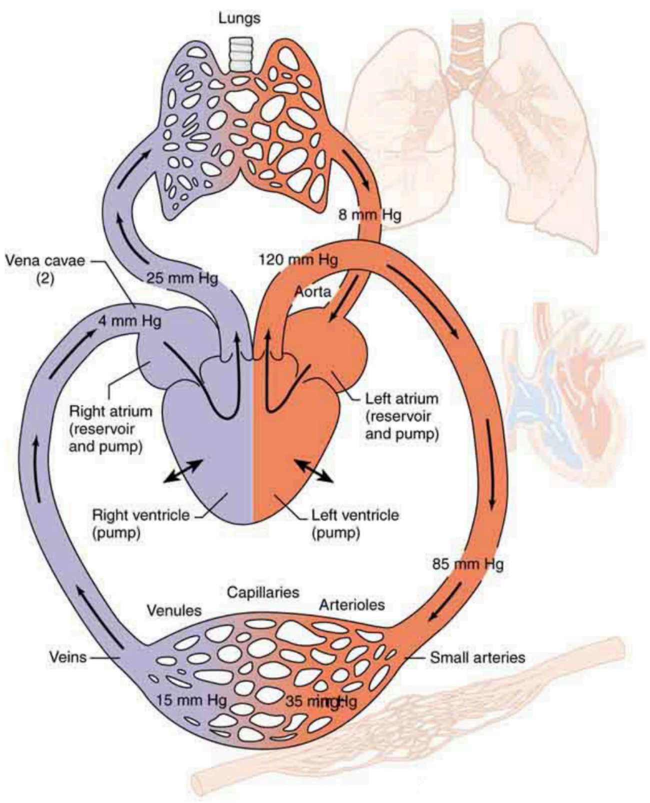
- The two pumps in the heart increase pressure, and that pressure is reduced as the blood flows through the body
  - Basically, pressure difference is created and is then reduced by resistance
- Branching of vessels into capillaries allows blood to reach individual cells and exchange O_2, waste, etc. with them
  - The system has an impressive ability to regulate flow to individual organs, largely due to varying vessel diameters



- Each branching of larger into smaller vessels increases total cross-sectional area through which blood flows
    - eg. an artery with a cross-section of 1 cm^2 may branch into 20 smaller arteries, each with cross-sections of 0.5 cm^2, with a total of 10 cm^2
    - In that manner, the resistance of the branchings is reduced so that pressure is not entirely lost



- The blood velocity in aorta (diameter of 1 cm) is about 25 cm/s, while in the capillaries (diameter of 20 μm) the velocity is about 1 mm/s
  - This reduced velocity allows the blood to exchange substances with the cells in capillaries and alveoli in particular

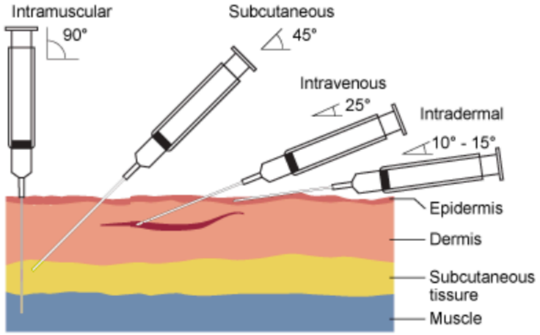


Measuring BP

- In routine blood pressure measurements, an inflatable cuff is placed on the upper arm at the same level as the heart
- Blood flow is detected just below the cuff, and corresponding pressures are transmitted to a mercury-filled manometer (sphygmo*manometer*)
- Typical BP of a young adult raises the mercury to height of 120 mm at systolic and 80 mm at diastolic (hence 120 over 80, or 120/80)

IV infusions

- Intravenous therapy is a medical process that administers fluids, meds & nutrients directly into a person's vein
  - Commonly for those who cannot or will not (reduced mental state, etc.) consume food or water by mouth
- Intravenous infusions are usually made with the help of the gravitational force



Example. (Previously a quiz item.) Assuming that the density of the fluid being administered is 1.00 g/mL, at what height should the IV bag be placed above the entry point so that the fluid just enters the vein if the blood pressure in the vein is 18 mm Hg above atmospheric pressure p_a? Assume that the IV bag is collapsible

- For the fluid to just enter the vein, its pressure at entry must exceed blood pressure in the vein (18 mm Hg above p_a). We need to find the height that corresponds to this gauge pressure
- Converting pressure into SI units (pascals), we have

$$p = 18 \text{ mm Hg} \times (133 \text{ Pa})/(1 \text{ mm Hg}) = 2400 \text{ Pa} = 2400 \text{ N/m}^2$$

- Isolating h from pressure-elevation definition $p = \rho g h$, we get

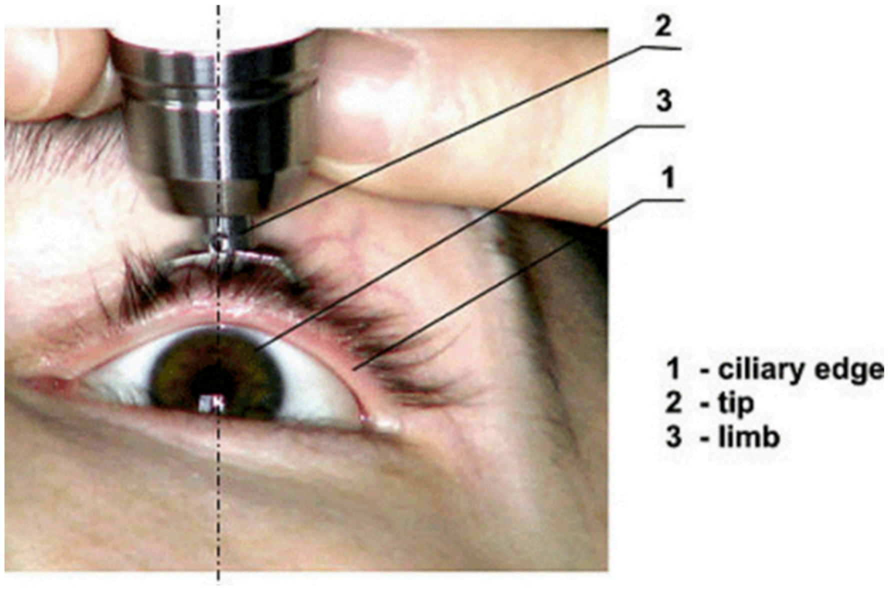
$$h = \frac{p}{\rho g} = \frac{2400 \text{ N/m}^2}{(10^3 \text{ kg/m}^3)(9.8 \text{ m/s}^2)} = 0.24 \text{ m}$$

  Note that $1 \text{ mL} = 10^{-6} \text{ m}^3$, and so $1 \text{ g/mL} = 10^3 \text{ kg/m}^3$

- The IV bag must be placed at 0.24 m above the entry point into the arm for the fluid to just enter the arm. Generally, the bags are placed higher than this
  - Notice that the bags used for blood collection are placed below the donor to allow blood to flow easily from the arm to the bag, which is the opposite of this example

Pressure in the eye 👀

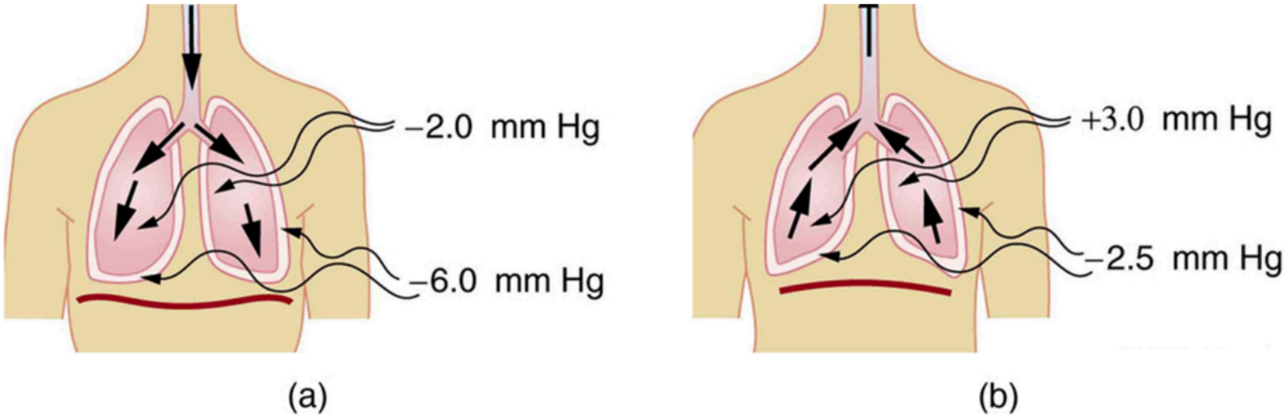
- The shape of the eye is maintained by fluid pressure called **intraocular pressure** (normally 12.0 to 24.0 mm Hg)
  - Measured by a **tonometer**
- When the circulation of fluid in the eye is blocked, it can lead to a buildup in pressure, a condition called **glaucoma**



- The net pressure can become as great as 85.0 mm Hg, an abnormally large pressure that can permanently damage the optic nerve, which converts to 6.8 N of force, equivalent to a 680-g mass resting on your eye (more than 0.5 kg!)
- If the intraocular pressure is high, the eye will deform less and rebound more vigorously than normal
- People over 40 years of age are at greatest risk of developing glaucoma and should have intraocular pressure tested routinely
  - The routine usually involves exerting a force on the anesthesized eye over some area (a pressure)

Pressure in the lungs 🫁

- Pressure inside lungs increases and decreases with each breath. It is controlled by several mechanisms
  - Muscle action in diaphragm and rib cage for inhalation
  - Surface tension in alveoli ($+p$) opposing inhalation



- (a) During inhalation, muscles expand the chest, and the diaphragm moves downward, reducing pressure inside lungs to less than atmospheric (negative gauge pressure)
  - Pressure between the lungs and chest wall is even lower to overcome positive pressure created by surface tension in lungs
- (b) During gentle exhalation, the muscles simply relax and surface tension in the alveoli creates a positive pressure inside the lungs, forcing air out
  - Pressure between the chest wall and lungs remains negative to keep them attached to the chest wall, but it is less negative than during inhalation

- The gauge pressure in the liquid attaching the lungs to the inside of the chest wall is thus negative, ranging from -4 to -8 mm Hg during exhalation and inhalation, respectively
- If air is allowed to enter the chest cavity, it breaks the attachment, and one or both lungs may collapse
  - Suction is applied to chest cavity of surgery patients and trauma victims to reestablish negative pressure and inflate the lungs

Pressure in spine and skull 💀

- Normally, there is a 5 to 12 mm Hg pressure in the fluid surrounding the brain and filling the spinal column
- This cerebrospinal fluid serves many purposes, one of which is to supply flotation (buoyant force)
- If there is a loss of fluid, the brain rests on the skull, causing severe headaches, constricted blood flow, and serious damage
- Spinal fluid pressure is measured via a needle inserted between vertebrae that transmits pressure to a measuring device

Pressure in bladder 🚽

- Bladder pressure is one of which we are often aware (toilet!)
  - It climbs steadily from zero to about 25 mm Hg as the bladder fills to its normal capacity of 500 cm^3
  - This pressure triggers the **micturition reflex**, stimulating the feeling of needing to urinate
  - Also causes muscles around bladder to contract, raising pressure to over 100 mm Hg, accentuating the sensation
- High bladder pressure (sometimes caused by obstruction) can force urine back into kidneys, causing potentially severe damage

Pressure in skeletal system 🦴

- These pressures are the largest, due both to the high values of initial force, and small areas to which force is applied eg. joints
  - eg. when a person lifts an object *improperly*, a force of 5000 N may be applied to an area as small as 10 cm^2 between the vertebrae in the spine, equivalent to about 5×10^6 Pa
  - This can damage both the spinal discs (the cartilage between vertebrae), as well as the bony vertebrae themselves

- Most causes of excessive pressure in skeleton can be avoided by lifting properly and avoiding extreme physical activity

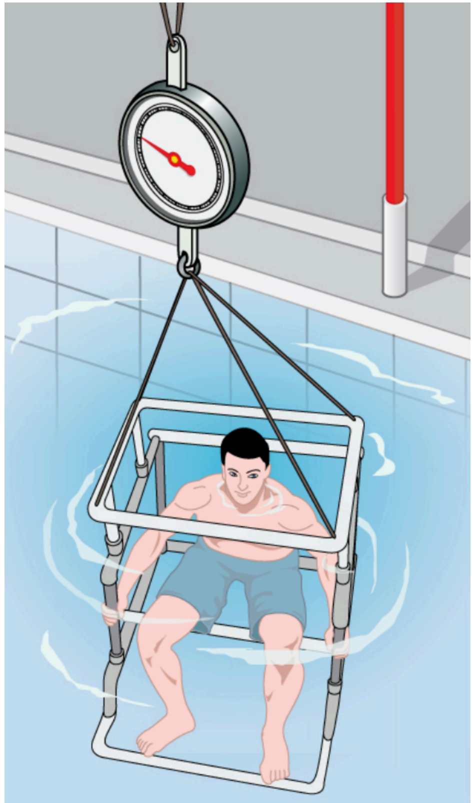
Pressure in other parts of body 🧍

- Stomach pressure behaves much like bladder pressure and is tied to the sensation of hunger
- Pressure in the relaxed esophagus is normally negative because pressure in the chest cavity is normally negative
- Positive pressure in the stomach may thus force acid into the esophagus, causing *heartburn*
- Pressure in the middle ear can result in significant force on the eardrum if it differs greatly from atmospheric pressure, eg. scuba diving

Buoyancy of the body

Measuring body density

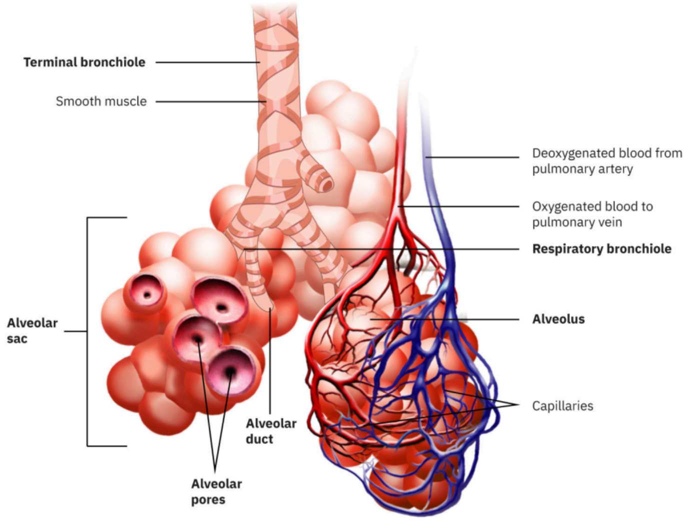
- Body density is one indicator of a person's percent body fat, usually of interest in medical diagnostics and athletic training
- One way to accurately measure this is thru a hydrostatis weighing device
  - Other ways include skinfolds, bioelectrical impedance, DEXA scan, MRI/CT scans



- A subject in a hydrostatis weighing device are weighed while completely submerged (employs buoyancy)
  - The subject must completely empty their lungs and hold a metal weight in order to sink
  - Corrections are made for the residual air in the lungs, which are measured separately, and the metal weight
  - Their corrected submerged weight, their weight in air, and pinch tests of strategic fatty areas are used to calculate the percent body fat

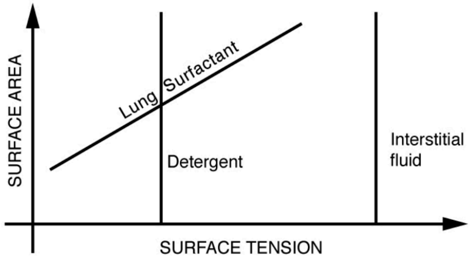
Bubbles in the lungs

- Our lungs contain hundreds of millions of mucus-lined sacs called **alveoli**, which are very similar in size and about 0.1 mm in diameter
- Bronchial tubes in lungs branch into ever-smaller structures, finally ending in alveoli (which act like tiny bubbles)



- The surface tension of their mucous lining *aids* in exhalation, and *can prevent* inhalation if too great

- You can exhale without muscle action by allowing surface tension to contract these sacs. Even if there is paralysis, surface tension in the alveoli will expel air from the lung
- The surface tension for lung surfactant decreases with decreasing area
    - Ensures that small alveoli do not collapse and large alveoli are not able to over-expand



- If water gets into the lungs, the surface tension is too great and you cannot inhale. This is a severe problem in resuscitating drowning victims, and newborns with *hyaline membrane disease*

Quiz time 🕐

React with Mike 📺

- Watch this react vid by Doctor Mike on The Pitt's ep. 2
- Find a part in the video that has anything to do with fluids
- Relate this part to what we learned from either fluid statics or dynamics. Do this in 1-2 paragraphs. Indicate timestamp

Doctor Mike (2025), "Doctor Reacts To The Pitt | Episode 2", https://youtu.be/pUTe9vsZ8do