Physiology Undergraduate League of Students

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lecture #:	date:	professor:
21	February 20, 2017	Dr. Guevara

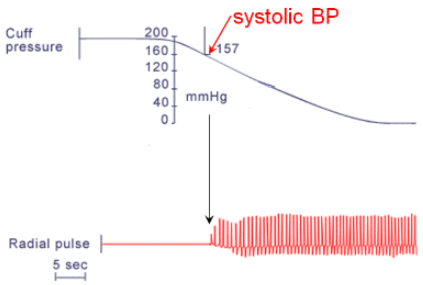
CARDIOVASCULAR

BLOOD PRESSURE

Direct Methods

- Stephen Hales (1733) - measured a horse's blood pressure by sticking a long glass tube into its artery

Indirect Methods



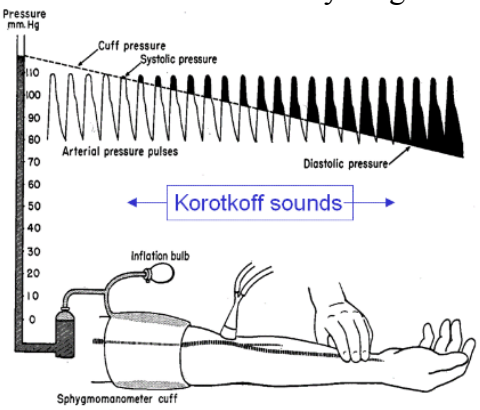
- Indirect methods all use a blood pressure cuff (otherwise called aneroid sphygmomanometer) that is put around the arm of the patient. It also includes an aneroid gauge, that shows the pressure, and an inflating bulb, that you manually pump.
- There are three indirect methods: palpation, auscultation and the oscillometric method.

Palpation: using touch to find systolic BP

- The cuff is pumped to a pressure higher than the systolic pressure in the artery → artery closes and blood flow is zero.
- There is a valve that lets out air slowly when it is opened, so when you're ready, you can bring the pressure in the cuff down
- As pressure slowly falls, you feel for the first pulse, which indicates the arterioles are open again and blood flow is back = this is <u>systolic</u> BP

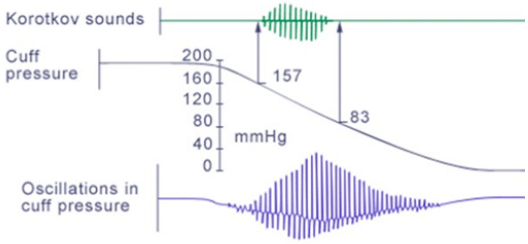
Auscultation: using sound to find systolic and diastolic BP: listen to chest and breath – place stethoscope on the brachial artery (artery in upper arm) while using an aneroid sphygmomanometer

- If you pump cuff up to high level – there is no flow through artery and you hear nothing.
- If you don't have cuff, you still hear nothing because the flow is laminar – too smooth to hear anything.
- To hear <u>Korotkoff Sounds:</u>
  - Using cuff, increase the cuff pressure to a pressure above the systolic pressure. This closes the artery off so the blood flow goes to zero. We will be unable to hear anything at this point.
  - When you release the cuff pressure slowly, blood will start to flow through the artery, but into a barely opened vessel.
    - You get turbulent flow since it's a thin tube, and you can hear this sound = <u>Systolic</u> BP
  - The pressure of cuff continues to slowly lower. Eventually the pressure becomes lower than the diastolic pressure; the artery is fully open and it's back to laminar flow, so you hear nothing again.
    - The pressure at which you start to hear nothing = <u>Diastolic</u> BP



Oscillometric Method: use a little device with a cuff attached to it; the machine has a pump and a sensor.

- Pump inflates cuff and then deflates it. There is a pressure sensor in the cuff that sends info back to computer – so you are in fact recording the pressure in the cuff!
- When you look at these pressures, you see oscillations in this pressure before the pressure is at the systolic pressure (see



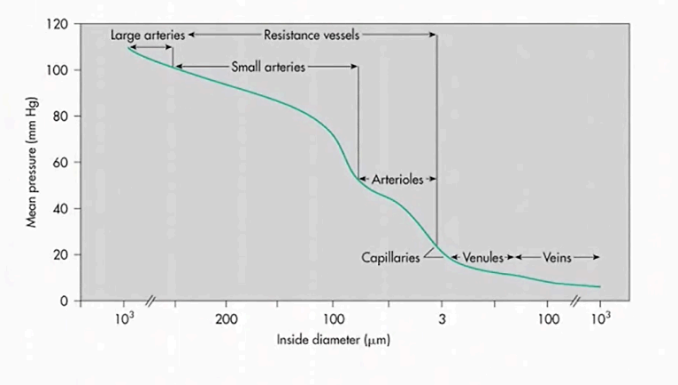
picture) and they persist at pressures below the diastolic pressure (see picture).
- From the slope of the oscillations, the systolic and diastolic pressures can be calculated.
- Nominal BP: 120/80 mmHg (systole/diastole)

Total Peripheral Resistance (otherwise SYSTEMIC VASCULAR RESISTANCE)
- TPR is the combined resistance of all the organs on the systemic side of our circulation. This is the resistance that our left ventricle has to pump against.
- Perfusion pressure for systemic circulation = Pressure in Aorta – Pressure in Right Atrium. Therefore, the total peripheral resistance is = Mean Arterial Blood Pressure – Pressure in Right Atrium/cardiac output (flow). This is based on the fact that flow = pressure/resistance. Because the pressure in the right atrium is so tiny, you can also say that TPR = Mean arterial blood pressure/cardiac output. You can also rearrange this equation:
  - BP(mean) = cardiac output x TPR
  - **BP (mean) = heart rate x stroke volume x TPR** -> SUPER important equation!
  - If you want to change mean arterial pressure, you need to change one of the factors on the right of the above equation.

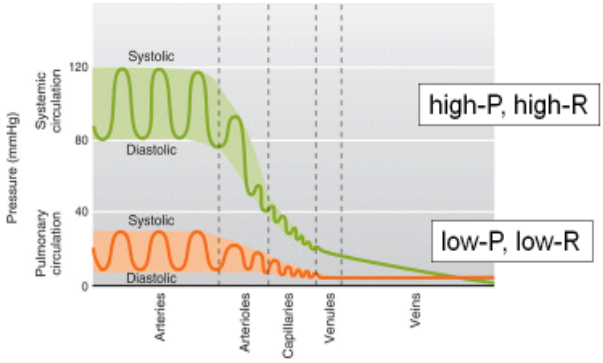
PERFUSION PRESSURE AND FLOW
- Perfusion pressure for an organ = Arterial pressure – Venous pressure or again, you can remove venous pressure, and just say its equivalent to the arterial pressure
- Therefore, flow to an organ = arterial pressure/resistance

$$\text{flow} = \frac{\text{perfusion pressure}}{R} = \frac{P_a - P_v}{R} \cong \frac{P_a}{R}$$

- The pressure in the aorta is 100mmHg – as you move through large arteries, it only drops by a few mm because there is barely any resistance due to the large size of the arteries.
- But when the blood drops down to arterioles, that's when there's lots of resistance and thus big drops in pressure! Thus by the time you get to venules and veins, the pressure is very low.

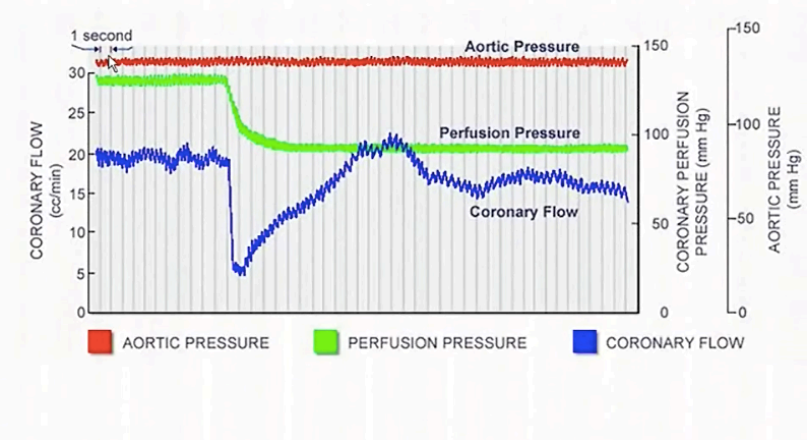


PULMONARY VASCULAR RESISTANCE
- When you're in the arteries, you have an arterial blood pressure wave form that goes from 120 to 80mmHg for the systemic circulation. But as you work your way to the arterioles, the size of this fluctuation goes down and by the time you get to capillaries, the pressure is very steady.
- In the pulmonary circulation, the mean pulmonary pressure is only 15mmHg vs. 100mmHg for systemic. However, the flow is the same and thus resistance here is 10x smaller.
- The systemic circulation = high pressure and high resistance
- The pulmonary circulation = low pressure and low resistance

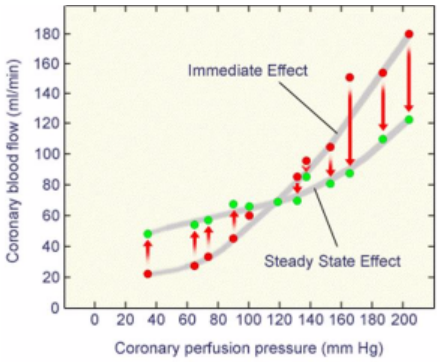


(FLOW) AUTOREGULATION

- Crucial organs auto-regulate **flow**: brain, heart, kidneys, etc.
  - If arterial pressure drops, body needs to bring flow back up or else you die. Therefore, the flow is auto-regulated.



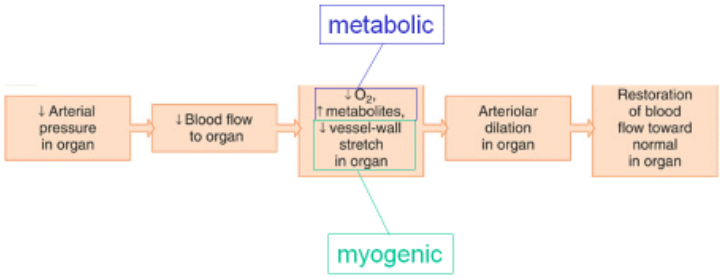
- Experiment: we buy a dog. In the dog's heart, the right and left coronary artery feed the heart with oxygen. We stick catheters into arteries and connect the other end to the pump so we can control the pressure in the arteries.
- We put the pressure to a reasonable value, bring the pressure in the coronary arteries down, which brings the perfusion pressure down and we see what happens.
- The aortic pressure in the dog doesn't change. After the perfusion pressure is brought down, the flow drops (see blue line) but afterwards, the flow goes back up to normal! What?
- The flow dropped to begin with because we decreased the perfusion pressure. But why did it come back up? Resistance fell! There was a dilation in the arterioles, causing resistance to fall, despite the fact that perfusion pressure is lower.
- If you increase the perfusion pressure, flow goes up and then returns to normal because of a constriction of arterioles.



- Key point of figure to the right ->: large range of pressures (around 40-120) where flow doesn't change too much = auto-regulation
- If coronary perfusion pressure is 0, what is flow? Zero!

TWO MECHANISMS OF AUTOREGULATION

- There are two mechanisms that change resistance! The two mechanisms operate concurrently.



1. Metabolic

- Stimulus is a change in arterial pressure
- If there is a fall in arterial pressure, there is a decrease of blood flow to organ, which results in a decrease in PO2 concentration in the tissue and increase in concentration of metabolites (waste products). This causes smooth muscles of arterioles to dilate.

2. Myogenic

- At the same time, if you decrease arterial pressure in organ, the amount of stretch in walls of vessels decreases and vascular smooth muscle has a property where if the stretch goes down, it relaxes the smooth muscle = dilation of arteriole = resistance will fall through Poiseuille's Law -> this restores the flow of blood
  - Poiseuille's law, $R \sim 1/r^4$

LOCAL METABOLIC CONTROL OF BLOOD FLOW

- The metabolic mechanism auto-regulates but it also does local metabolic control of blood flow.
- In auto regulation, the stimulus = change in BP. Here, the stimulus is that the organ changes its metabolic organ activity.
  - If you think more/exercise: increase need for O_2 → P_{O2} falls → increase in concentration of waste products → they cause dilation in organ → increase blood flow to organ
  - Happens locally: in the organ itself = it doesn't need nerves or anything else -> hence why it's called local control
- Hyperemia: increase oxygen needs for tissue → increased blood flow

WHY IS HEART RATE – AND ITS CONTROL – IMPORTANT?

$$CO = HR \cdot SV$$

- CO = HR * SV
  - Increase HR, SV or both to increase Cardiac Output
- BP(mean) = CO x TPR otherwise, HR x SV x TPR. This will be on the exam. KNOW IT!!
- But how do you change HR, SV or TPR? Through the body's systems!

$$BP_{mean} = CO \cdot TPR$$
$$= HR \cdot SV \cdot TPR$$

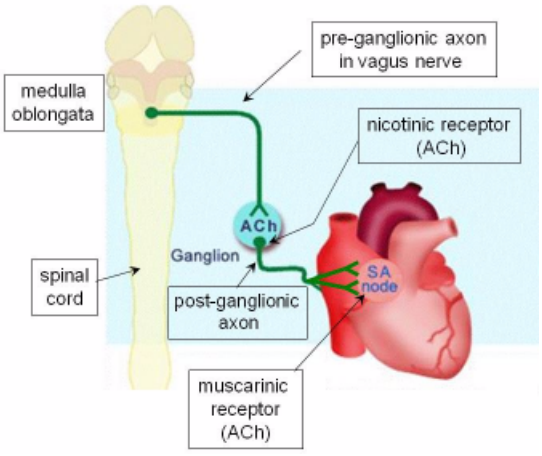
NEURAL CONTROL OF HEART AND VESSELS

Autonomic System

- Consists of: Parasympathetic and Sympathetic nervous system
- Usually if you increase activity in one system, the other decreases = but this is not true all the time
- Involuntary = autonomic system -> it is not in voluntary control. Just does its own thing.

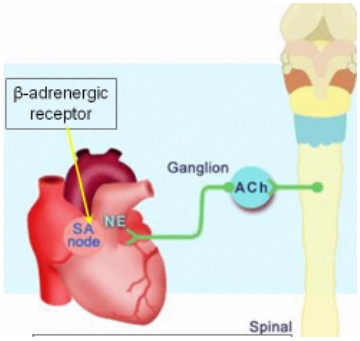
Parasympathetic Control of HR

- In the autonomic system, you see 2 axons: pre-ganglionic and post-ganglionic
- There is a cell body in the brain stem that sends out an axon to the ganglion and it synapses with a cell here. That neuron sends off the post-ganglionic neuron to the SA node and there is a synapse between nerve terminals of post-ganglionic axon and SA node cell.
  - Note at the first synapse, ACh is dumped onto a nicotinic receptor and at the second synapse, it's dumped onto a muscarinic receptor (throwback to 209!)
  - Anyways, ACh dumping itself onto the muscarinic receptor slows down the heart rate.



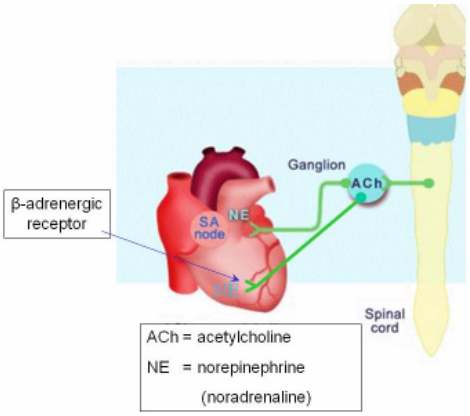
- So parasympathetic system slows down your heart rate.
- Drug atropine: it's a muscarinic antagonist → if heart rate (HR) and BP are low, after injected, it binds to the muscarinic receptor on the SA node → Ach can't bind because receptor is occupied → less ACh bound = increase heart rate
  - Used for sinus bradycardia
  - Increase in heart rate increases BP as per formula from before.

Sympathetic Control of Heart Rate



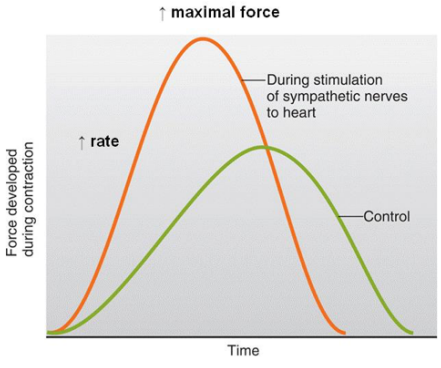
- 2 axons: Pre-ganglionic and post-ganglionic
- Two things are different here versus before:
  - Cell body in spinal cord not brain
  - Neurotransmitter is not acetylcholine ACh – it's norepinephrine NE; they bind to beta-adrenergic receptor
- The binding of NE to its receptor does a few things: it increases size of calcium current, more calcium flows into cell, Ca^{++} in cell goes up, and force of contraction goes up and HR goes up
- Here, NE binding to SA node causes an increase in heart rate – this is the sympathetic control!
- Beta agonist drug: similar to norepinephrine (binds same receptor) = increases cardiac output and BP, etc.
- Beta antagonist (beta blocker): heart rate and everything else slows because it prevents NE from binding its receptors
  - Beta blocker is popular
- When HR drops, what happens? Mean arterial pressure drops.

Sympathetic Control of Contractility



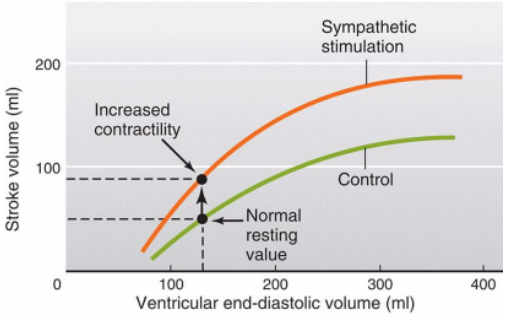
- Sympathetic system controls contractility, not parasympathetic!
- Axons that go down to SA node also go down on the ventricular muscle. And here, NE binds to its receptor in the same way as we saw with the SA node. But the function of this innervation is different:
  - Increase size of Ca^{++} current = Increase amount of free Ca^{++} = Increase force of contraction = SV increases, CO increases, BP increases = everyone is happy!!!
- Beta agonists increase HR and stroke volume = BP goes up
- Beta antagonists -> decrease BP.

INCREASED CONTRACTILITY



- If you stimulate the sympathetic nerves that go to the heart – you see that maximal force of contraction increases, rate at which force is developing increases and duration of systole decreases.

- Now look at second graph
- Starling's Law: if you increase the filling of the ventricle, you increase the amount of stretch in the walls of the ventricle and the force of contraction increases and SV increases. So the more and more you fill the ventricle, the more you move along the green curve and the more SV increases. This involves a stretch BEFORE you start contraction – cardiac muscle has a property where if you stretch it, force of contraction goes up.
- In contractility: you fill up the ventricle to a given volume and you are at the normal resting value. If you stimulate sympathetic nerves that go to the heart, you will get stronger contractions and SV goes up to higher value (see new point).
- When you exercise, both systems discussed above (Starling + contractility) occur to increase SV and force of contraction.



WHY CHANGE VESSEL DIAMETER?

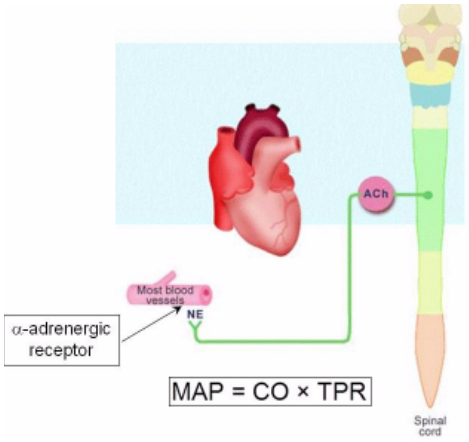
- To set appropriate flow for each organ
- Auto-regulation (in exercise from example)
- To maintain mean BP: if it falls, you want it higher; but if it's too high, you want it lower

Poiseuille's Law: $R \sim 1/r^4$

- Decrease radius by 10%, R increases 60%
- Increase radius by 10%, R goes down 70%
- Shows that small changes in radius r translate into big changes in resistance R. Math.

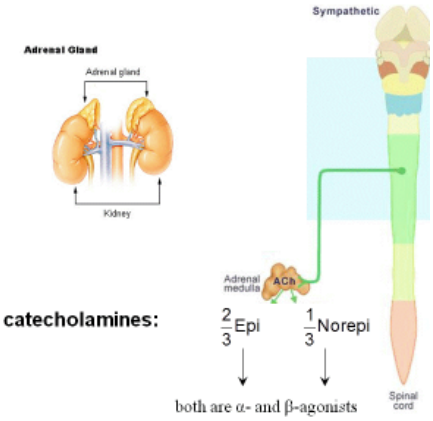
NEURAL CONTROL OF VESSEL SIZE

Sympathetic Control of Vessel Tone



- Almost all blood vessels in your body are innervated by the sympathetic nervous system. This doesn't include capillaries ☹ They have no smooth muscle!
- Same thing as before that we see here: ACh, norepinephrine, etc. But difference = the receptor on the cell is an alpha-adrenergic receptor!
- After NE binds to the receptor, this increases calcium concentration and this increases force of contraction. So this squeezes down on arterioles, increase TPR, increase Mean Arterial Pressure, increase BP, everyone is happy!
- Alpha agonist: in a patient with extremely low BP, it can save the life of a patient -> squeezes down on arterioles! It affects **TPR!!** Thus the mean arterial BP goes up and patient can live!
- Alpha blocker: binds to receptor and occupies it -> vessel is less constricted. They are used to treat high BP in particular circumstances.

ADRENAL GLANDS



- Make Norepinephrine NE and Epinephrine E
- Sympathetic nervous system: no post-ganglionic axon here! The cells in the adrenal medulla just secrete hormones into circulation instead.
- Both NE and E are alpha and beta-agonists
  - ➢ They bind to the appropriate receptors; dose depends on concentration
- GOOD LUCK