REGIONAL BLOOD FLOW

SKELETAL MUSCLE BLOOD FLOW:

- Extreme increases in blood flow through skeletal muscle during exercise (rising to 50-80mL/min/100g of muscle)
- **Flow in muscles increases and decreases with each muscle contraction**
    - **As a result of compression of the blood vessels by the contracted muscle**
- **Muscle capillaries open during strenuous exercise – CAPILLARY RECRUITMENT**
    - Opening of dormant capillaries also diminishes the **distance** that oxygen and other nutrients must diffuse
- LOCAL REGULATION:
    - Decreased oxygen in muscle greatly enhances flow
    - Tremendous increase in muscle blood flow is caused primarily by **local chemical effect** acting directly on the muscle arterioles to cause vasodilation
    - Reduction in O2:
        - Local arteriolar dilation because not enough O2 to maintain contraction
        - Also, there is an accumulation of vasodilator substance (less evidence)
- **Vasodilator theory: product of metabolism (e.g. adenosine) → vasodilation**
- **Oxygen lack theory: oxygen needed to maintain vascular smooth muscle tone**

- NERVOUS CONTROL OF MUSCLE BLOOD FLOW:
    - Sympathetic vasoconstrictor nerves:
        - **Nerve endings secrete noradrenaline, which results in decreased blood flow through resting muscles to one half normal**
            - **This represents poor vasoconstriction compared to other areas of the body BUT still is of significance in circulatory shock**

CORONARY CIRCULATION:

- PHYSIOLOGIC ANATOMY OF THE CORONARY BLOOD SUPPLY:
    - Left coronary supplies mainly the anterior and left lateral portions of the left ventricle
    - **Right coronary supplies most of the right ventricle and posterior part of the left ventricle**
    - Most of nutritive blood supply is via penetrating arteries into muscle mass
- NORMAL CORONARY BLOOD FLOW:

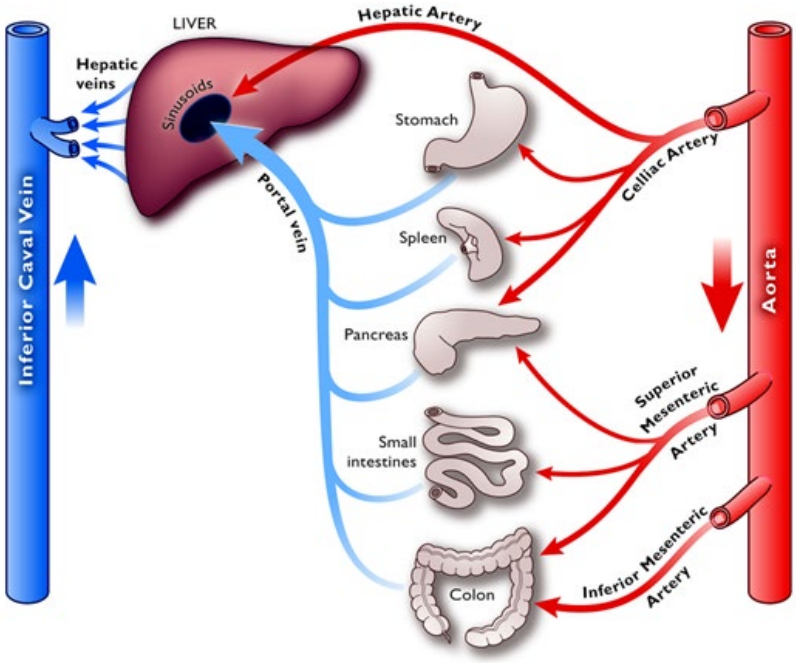
- Resting coronary blood flow is 225mL/min (4-5%)
- **Resting coronary blood flow = 5% of CO**
- **Renal blood flow = 25% of CO**

- PHASIC CHANGES IN BLOOD FLOW:
  - Capillary blood flow in the left ventricle falls to a low value during systole, which is opposite to the flow in other vascular beds of the body
  - Reason is strong compression of the LV muscle around intramuscular vessels
  - During diastole, the cardiac muscle relaxes and no longer obstructs the blood flow, so that blood flows rapidly during all of diastole
- **CONTROL OF CORONARY BLOOD FLOW:**
  - **Local metabolism** is the primary controller
    - In response to cardiac muscles need for nutrition
    - When vigour of contraction is increased, rate of coronary blood flow increases simultaneously
  - Again **Oxygen demand** is a major factor
    - Blood flow is regulated almost exactly in proportion to the need of the cardiac musculature for oxygen
    - Again, either it is decreased oxygen leading to inability of vessel to stay contracted versus vasodilatory substance (adenosine, ATP, hydrogen ions, CO_2, bradykinin, potassium, prostaglandins) that cause local dilation
  - Nervous control:
    - Direct effects:
      - Acetylcholine from the vagus and adrenaline/noradrenaline from the sympathetic nerves
    - Indirect effects result from changes in local metabolism
    - Parasympathetic stimulation only has slight direct effect to coronary vessels
    - **Much more extensive sympathetic stimulation**:
      - Numerous **alpha receptors that respond to noradrenaline with vasoconstriction (epicardial vessels)**
      - Penetrating muscle arteries have numerous **beta receptors, which respond to adrenaline with dilation**
    - **Coronary arteries:**
      - **NA on α-AR – constriction**
      - **A on β-AR – constriction**

SPLANCHNIC CIRCULATION:

- INCLUDES:
  - Blood flow through the **gut, spleen, pancreas and liver**

    - Designed so that blood that flows from gut, spleen and pancreas via the portal vein to the liver
- ANATOMY:
    - Superior and inferior mesenteric arteries supply the walls of the small and large intestines by way of an arching arterial system
    - On entering the gut wall, the arteries branch and send smaller arteries circling in both directions around the gut



- **FACTORS EFFECTING BLOOD FLOW IN THE G.I.T.:**
    - AGAIN, DIRECTLY RELATED TO LOCAL ACTIVITY:
        - During active absorption of nutrients, blood flow in the villi and adjacent regions of the submucosa is increased
        - Likewise, with increased motor activity, e.g. after a meal, the blood flow increases

- POSSIBLE CAUSES OF INCREASED BLOOD FLOW:
    - **VASODILATOR SUBSTANCES RELEASED DURING DIGESTION**:
        - Cholecystokinin, VIP, gastrin and secretin
    - **GIT GLANDS**:
        - Release kallidin and **bradykinin**, both powerful vasodilators
    - **DECREASED OXYGEN CONCENTRATION**:
        - Increase intestinal blood flow at least 100%
        - Related to metabolic rate of the gut

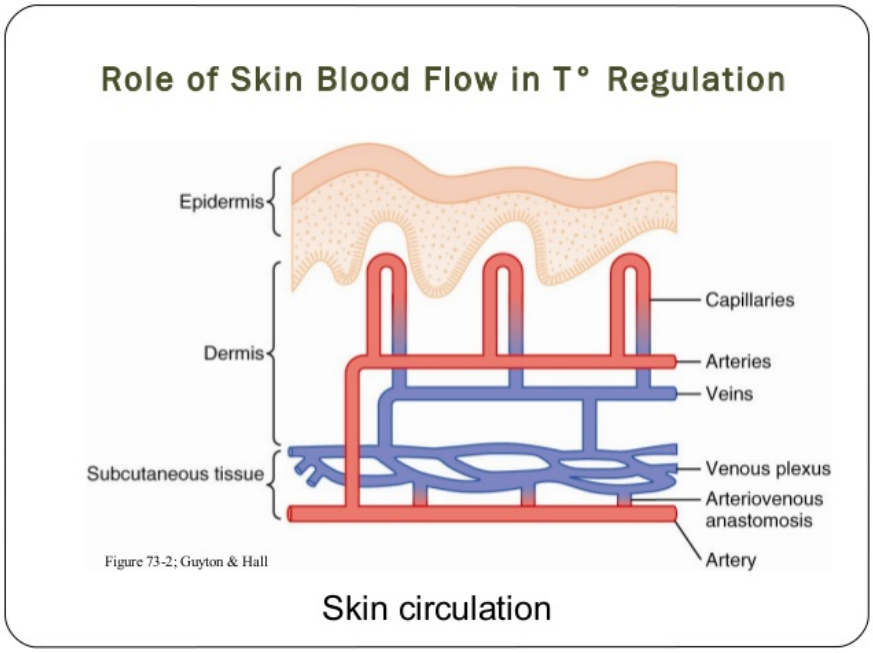
- COUNTERCURRENT BLOOD FLOW IN THE VILLI:
    - Arterial flow into the villous and venous flow out of it are in directions opposite to each other

    - These vessels lie in close apposition, so 80% of oxygen "short-circuits" into the venules and as such will not be available for local metabolic functions in the villi
    - Normally this is not harmful, but if blood flow severely limited, villous necrosis can occur

- NERVOUS CONTROL:
    - **Parasympathetic nerves to the stomach and lower colon increase local blood flow at the same time that it increases local glandular secretion**
        - Increased blood flow probably secondary to increased glandular activity
    - **Sympathetic stimulation has a direct effect on essentially all the GIT to cause intense vasoconstriction of the arterioles with greatly decreased blood flow**
        - **AUTOREGULATORY ESCAPE** normally occurs after a few minutes, with ischaemic vasodilator effects becoming predominant in their effect on local blood flow
    - Shutting off splanchnic blood flow becomes critical in heavy exercise, increasing venous return and thus cardiac output

SKIN CIRCULATION:

- Blood vessels are distributed profusely immediately beneath the skin
    - Especially important is a **continuous venous plexus that is supplied by inflow of blood from the skin capillaries and via highly muscular arteriovenous anastomoses**
    - Rate of blood volume **can vary to as much as 30% of cardiac output**, causing heat to be conducted from the skin with great efficiency
- Heat conduction to the skin is controlled by the degree of vasoconstriction of the arterioles and arteriovenous anastomoses to the venous plexus of the skin
- This **vasoconstriction in turn is controlled almost entirely by the sympathetic nervous system** in response to changes in body core temperature and changes in environmental temperature



CEREBRAL BLOOD FLOW:

- REGULATION OF CEREBRAL BLOOD FLOW:
  - Cerebral blood flow is highly related to the metabolism of the cerebral tissue
  - At least three metabolic factors have potent effects in controlling cerebral blood flow
    - **CARBON DIOXIDE** CONCENTRATION
    - **HYDROGEN** ION CONCENTRATION
    - **OXYGEN** CONCENTRATION
- CARBON DIOXIDE AND HYDROGEN ION:
  - CO_2 is believed to increase cerebral blood flow ALMOST ENTIRELY by first combining with water in the body fluids to form carbonic acid, with subsequent dissociation of the acid to form **hydrogen ions**
    - The **hydrogen ions then cause vasodilation of the cerebral vessels**
    - The dilation is almost directly proportional to the increase in hydrogen ion concentration up to a blood flow limit of about twice normal
  - **Increased hydrogen ion concentration greatly DEPRESSES NEURONAL ACTIVITY**
    - The increased blood flow is crucial and fortuitous as both carbon dioxide and other acid-forming substance away from the brain tissues
    - This reduces the hydrogen ion concentration back towards normal

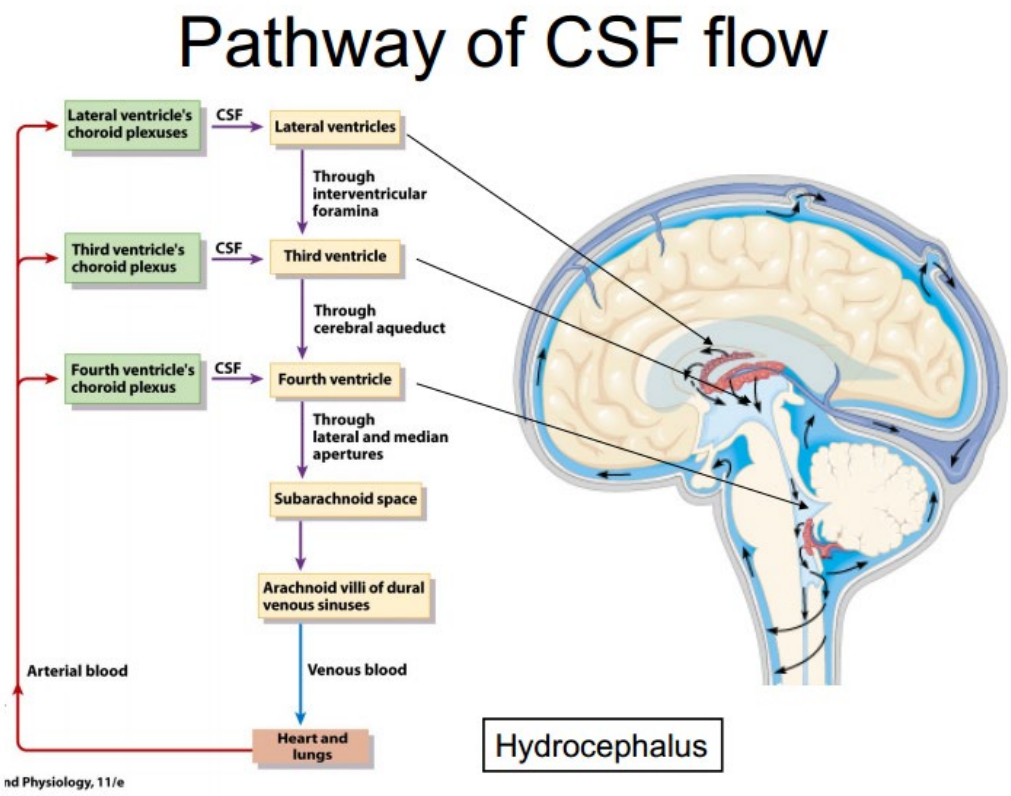
    - **H+ ions depress normal neuronal activity**
    - **H+ cause marked cerebral vasodilation**
    - **Therefore mediates its own mechanism of increased flow and clearance**

- OXYGEN CONCENTRATION:
    - If the blood flow to the brain ever becomes insufficient to supply the required amount of O2, the oxygen deficiency mechanism for causing vasodilation immediately causes vasodilatation, returning blood flow and transport of oxygen to the cerebral tissues to near normal
    - Experiments have shown that a decrease in cerebral tissue PO2 below about 30mmHg (normal value is about 35-40) immediately begins to increase cerebral blood flow
- AUTOREGULATION OF CEREBRAL BLOOD FLOW WHEN ARTERIAL BP CHANGES:
    - **Cerebral blood flow also is autoregulated extremely well the arterial pressure limits of <u>60-140mmHg</u>**
    - If the arterial pressure falls below 60mmHg, cerebral blood flow then does become severely compromised
    - If the pressure rises above the upper limit of autoregulation, the blood flow increases rapidly and can cause severe overstretching or rupture of cerebral blood vessels, sometimes resulting in serious brain oedema or cerebral haemorrhage
- ROLE OF THE SYMPATHETIC NERVOUS SYSTEM:
    - The **cerebral circulatory system has STRONG sympathetic innervation** that passes upward from the **superior cervical sympathetic ganglia in the neck and then into the brain along with the cerebral arteries**
    - This innervation supplies both the large superficial brain arteries and the small arteries that penetrate into the substance of the brain
    - **CAN BE OVERRIDED BY THE AUTOREGULATION MECHANISM**
        - Thought to play little role in regulation of blood flow
    - RECENT EVIDENCE:
        - Shown that when arterial pressure rises acutely to an exceptionally high level (e.g. during strenuous exercise), the SNS normally constricts the large and intermediate-sized brain arteries enough to prevent the high pressure from reaching the smaller brain blood vessels

<u>CEREBROSPINAL FLUID SYSTEM:</u>

- CSF is found in the ventricles of the brain and also in:
    - Cisterns around the outside of the brain
    - The subarachnoid space around both the brain and the spinal cord
    - All these chambers are connected with one another and the pressure of the fluid is maintained at a remarkably constant level
- Main function of the CSF is to cushion the brain within its solid vault

- FORMATION, FLOW AND ABSORPTION OF THE CSF:
  - Formed at a rate of about **500mL each day, which is three to four times as much as the total volume that is required**
  - About 2/3 or more originate as a secretion from the **CHOROID PLEXUSES** in the four ventricles (mainly in the **lateral ventricles**)
    - Additional amounts of fluid are secreted by all the ependymal surfaces of the ventricles and the arachnoidal membranes
  - The fluid secreted in the lateral ventricles passes first into the third ventricle
    - Then flows downwards through the AQUEDUCT OF SYLVIUS into the fourth ventricle
    - Then passes out of the fourth ventricle through three small openings:
      - Two lateral "foramina of Luschka"
      - One median "foramen of Magendie"
    - The fluid then enters the **cisterna magna**:
      - A large fluid space that lies behind the medulla and beneath the cerebellum
    - The cisterna magna is continuous with the subarachnoid space that surround the entire brain and spinal cord
    - Almost all the CSF flows upward from the cisterna magna through the subarachnoid space surrounding the cerebrum
    - From here the fluid flows into the multiple arachnoidal villi that project into the large sagittal venous sinus and other venous sinuses of the cerebrum



- SECRETION BY THE **CHOROID PLEXUS**:
  - The plexus projects into:
    - Temporal horn of each lateral ventricle
    - The posterior portion of the third ventricle
    - The roof of the fourth ventricle
  - The secretion of fluid depends mainly on active transport of sodium ions through the epithelial cells that line the outsides of the plexus
    - Pulls large amounts of chloride ions
    - The two of these together increase the quantity of osmotically active sodium chloride in the CSF, which then causes almost immediate osmosis of water
  - Less important transport processes move small amounts of glucose into the CSF, and both potassium and bicarbonate ions out of the CSF into the capillaries
- ABSORPTION OF CSF THROUGH THE **ARACHNOIDAL VILLI**:
  - Conglomerates of villi form ARACHNOIDAL GRANULATIONS
  - The epithelial cells have **VESICULAR HOLES** that are large enough to allow relatively free flow of:
    - CSF
    - Dissolved protein molecules
    - Even particles as large as red and white blood cells into the venous blood

- LYMPHATIC FUNCTION OF THE PERIVASCULAR SPACE:
    - A small amount of protein leaks out of the brain capillaries into the interstitial spaces of the brain because no true lymphatics are present in brain tissue, this protein leaves the tissue mainly by flowing with fluid through the perivascular spaces into the subarachnoid spaces, to be absorbed through the arachnoidal villi
- **CSF PRESSURE:**
    - The normal pressure in the CSF system when on is lying in a horizontal position is **8-15cmH20**
    - REGULATION OF CSF PRESSURE BY THE ARACHNOID VILLI:
        - **Rate of formation of CSF is constant**
        - Conversely, the arachnoidal villi function like "VALVES" that allow CSF and its contents to flow readily into the blood of the venous sinuses while not allowing blood to flow backward
            - Normally CSF begins to flow into the blood when the pressure is about 1.5mmHg higher than the pressure of the blood in the venous sinuses
            - If the CSF pressure rises still higher, the valve open more widely, so that **under normal conditions, the CSF pressure almost never rises more than a few mmHG higher than the pressure in the venous sinuses**
        - **⇑CSF pressure → ⇑outflow in venous blood**
        - In disease states, the villi sometime become blocked by large particulate matter, by fibrosis or even by excesses of plasma protein molecule that have leaked into the CSF in brain diseases

    - HIGH CSF PRESSURE IN PATHOLOGICAL CONDITIONS:
        - Often a large brain tumour elevates the CSF by decreasing the rate of absorption of CSF into the blood
        - If the tumour is above the tentorium and becomes so large that it compresses the brain downward, the upward flow of fluid through the subarachnoid space around the brain stem where it passes through the tentorial opening may become severely restricted and the absorption of fluid by the cerebral arachnoidal villi is greatly curtailed
        - CSF pressure also rises considerably when haemorrhage or infection occurs in the cranial vault
            - In both of these conditions, large numbers of red and/or white blood cells suddenly appear in the CSF and they can cause serious blockage of the small channels for absorption through the arachnoidal villi

    - OBSTRUCTION OF FLOW:

- HYDROCEPHALUS means excess water in the cranial vault
- This condition is frequently divided into:
  - **COMMUNICATING HYDROCEPHALUS**:
    - Failure of resorption in arachnoid granulation
  - **NONCOMMUNICATING HYDROCEPHALUS:**
    - Block in the channels which conduct CSF so it doesn't make it to the SA space